COMPUTER IMPLEMENTATION OF OPSET— A SELF CALIBRATING WATERSHED MODEL

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By
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TO

MY PARENTS

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CERTIFICATE

This is to certify that the thesis entitled COMPUTER IMPLEMENTATION OF OPSET - A SELF CALIBRATING WATERSHED MODEL by Shyamal Kumar Ray is a record of work carried out under our supervision and that it has not been submitted elsewhere for a degree.

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DICTIONARY OF VARIABLES

AEX90	Antecedent Evaporation Index, Decay Rate = 0.90
AREA	Area of Watershed
BFRC	Base Flow Recession Constant
BIVF	Basic Interflow Volume Factor
BMIR	Basic Maximum Infiltration Rate Within Watershed
BUZC	Basic Upper Zone Storage Capacity Factor
CHCAP	Channel Capacity - Indexed to Basic Outlet
CN	1 = A.M., 2 = P.M.
CONOPT	Control Option
CSRX	Channel Storage Routing Index
DATE	Current Day of the Month
DAY	Current Day of the Year
DIV	Diversion Into Basin, Mean Daily Flow
DPET	Dated Potential Evapotranspiration
DPY	Days per Year
DRHP	Dated Recorded Hourly Precipitation
DRSF	Dated Recorded Streamflow
DRSGP	Dated Recorded Storage Gauge Precipitation
ETLF	Evapotranspiration Loss Factor
FIMP	Fraction of the Watershed Being Impervious
FSRX	Flood Plain Storage Routing Index
FWTR	Fraction of the Watershed Being Water
GWETF	Ground Water Evapotranspiration Factor
HOUR	Current Hour of the Day
HRF	First Hour of Loop
HRL	Last Hour of Loop
IFRC	Interflow Recession Constant
ISGRD	Current Storage Gauge Rainfall Day
IWBG	Index Number of Weather Bureau Precipitation Gauge

KRD	Counter for Reading Data Arrays
KWM	Kentucky Watershed Model
LZC	Lower Zone Storage Capacity
LZS	Current Lower Zone Storage
MEDCY	Month End Dates - Calendar Year
MNRC	Minimum Number of Rough Cycles
MONTH	Current Month of the Year
NCTRI	Number of Current Time Routing Increments
NFTR	Number of First Trip to Be Run For a Given Station Year
NLTR	Number of Last Trip To Be Run For a Given Station Year
NSGRD	Number of Storage Gauge Rainfall Days
OFMN	Overland Flow Manning's N
OFMNIS	Overland Flow Manning's N, Impervious Surfaces
OFSL	Overland Flow Surface Length
OFSS	Overland Flow Surface Slope
SIAC	Seasonal Infiltration Adjustment Constant
SIX	Current Storage Routing Index
SSQM	Sum of the Squares of the Monthly Flow Deviations
SUBWF	Subsurface Water Flow Out of the Basin
SUZC	Seasonal Upper Zone Storage Capacity Factor
SWM	Stanford Watershed Model
TRIP	Counter Specifying Program Portions
UZC	Upper Zone Storage Capacity
INTMR	Vegetative Interception - Maximum Rate
EAR	Last Two Digits of Current Year

SYNOPSIS

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COMPUTER IMPLEMENTATION OF OPSET - A SELF CALIBRATING WATERSHED MODEL

The present study is basically related to the implementation of OPSET, a self calibrating watershed model program, to the computer system IBM 7044 and IBM 370/155 and the application of this to an Indian watershed to find out the optimum set of some parameter values which influence the runoff in a watershed greatly. Test data are available to implement the program. For the Indian watershed the measurable watershed parameters and other climatological data are collected from different places.

Physical description of the watershed under study is given and the definitions and magnitudes of the measurable watershed parameter values are also presented here. While optimizing the parameter values the main objective was to synthesize the streamflow and hydrograph peaks as closely as possible with those of recorded values respectively. Synthesized and recorded values of flows are tabulated for comparison.

Changes are made inside the program where necessary and are given in this study. Ultimately the optimized parameter values obtained from OPSET program can be used in the Kentucky Watershed Model to use in ungauged watersheds.

CHAPTER I

INTRODUCTION

1.1 Hydrologic Cycle and Processes:

Hydrology is a branch of physical geography. It deals with the origin and distribution of the waters of the earth.

The study of hydrology starts with the concept of hydrologic cycle. Water evaporated from the oceans and the free water surface of the land mass is transported by moving air masses. Under proper conditions the vapour is condensed to form clouds, which, in turn, may result in precipitation. The precipitation which falls upon land is dispersed in several ways. Part of the water is returned to the atmosphere by the processes of evaporation and transpiration. Of the remaining part, a portion passes over and through the surface soil to the stream channels and other portion penetrates deeper inside the earth to become part of the earth's ground water supply. Under the influence of gravity these surface waters and ground waters always move towards the lower elevation but a substantial quantity of these return to the atmosphere through the processes of evaporation and transpiration.

A review of the hydrologic cycle, particularly of those processes which are important in governing runoff rates, provides the best background for understanding the model in

this study namely OPSET, the basic logics of which are dependent on the Stanford Watershed Model. The processes are described briefly in the following paragraphs.

Moisture held on vegetative surfaces is known as Interception Storage. This is dependent on type and density of vegetative cover. This reduces the runoff but its effect is less in large storms compared to small storms.

Precipitation not held by vegetative cover but held in hollows and behind ridges on soil surface is known as Depression Storage. This is also more effective in reducing runoff during small storms than during larger storms. Depression storage capacity is generally larger than interception storage capacity and is governed primarily by the roughness of the soil surface,human activity and watershed topography. Steep slopes reduce the depression storage capacity. In arid climate the less frequent runoff does not wash out the ridges and depression storage is greater.

A portion of the water in contact with the soil surface infiltrates into the soil which may return to the stream channel as Interflow or Baseflow or may be used by vegetation as evapotranspiration. Infiltration into the ground depends generally on the soil permeability, surface characteristics, presence or absence of vegetation, etc. But freezing of the upper zone, rising of the underground water table and low permeability at moderate depths are some factors for reduced infiltration rate.

High evapotranspiration rates will deplete the soil moisture between storms and consequently increase the infiltration rate. Evaporation from soil surfaces and exposed water surfaces depends on the degree of exposure, air temperature, water temperature, wind velocity, atmospheric pressure and percent solids in the water. Moisture loss through transpiration depends upon the degree of vegetative cover and other climatological factors. Urban development greatly increases the relative imperviousness of a watershed.

Water which doesnot percolate to the water table (to later appear as baseflow) may proceed toward the stream in two ways: (1) it may travel over the land surface (overland flow); or 2) it may travel partially through and partially above ground (interflow). The time lag of overland flow is governed by the slope, distance to the nearest collector stream and roughness of the soil surface. Overland flow is very rapid in impervious surfaces.

If the watertable is higher or if there is an impervious layer at a shallow depth, the interflow increases. Rapid flow through the soil layers is seen in most permeable soils. Quantity of interflow is dependent on the local infiltration capacity.

Overland flow, interflow, baseflow enter the channel system at different, scattered points in a watershed. The

channel inflows combine as they flow downstream and untimately reach the gauging station in the stream. This channel flow rate depends on the slope, size, shape, and hydraulic roughness.

A schematic diagram of the hydrologic cycle is shown in Fig. 1.

1.2 Mathematical Modeling and Analysis:

Full synthesis of the hydrologic cycle is practically impossible due to vast complexity of the systems involved in the study, inadequacy of the knowledge now available and the knowledge likely to exist in the foreseeable future. The other way is to solve the practical technological problems by establishing workable relationships between measurable parameters in the hydrologic cycle.

'Systems investigation' is needed in hydrology to establish quantitative relationships between precipitation and run-off, which can be used for 'reconstruction or prediction (ROP) of flood sequences and watershed yields. System investigation methods are (a) parametric and (b) stochastic. In the present work parametric study is done.

Parametric hydrology is the development of relationships among physical parameters involved in hydrologic events and the use of these relationships to generate, or synthesize, non-recorded hydrologic sequences [1]. Among all the studies

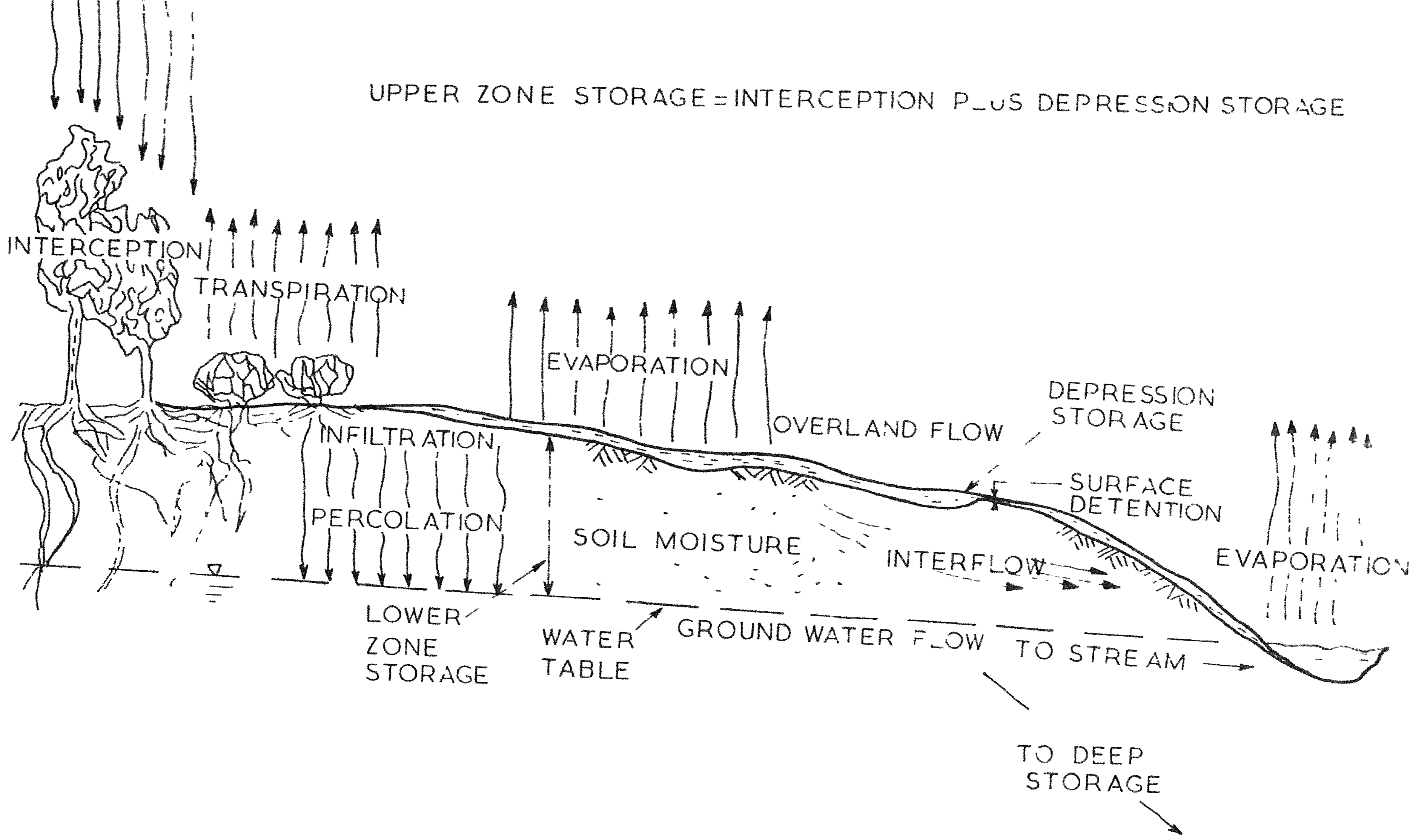


FIG.1 SCHEMATIC OF HYDROLOGIC CYCLE

made in parametric hydrology only the general non-linear analysis is independent of detailed knowledge of physical hydrology where emphasis is centred on topics of study. In the method of correlation analysis various combinations of variables are tested to explore the significance of their effects in the hydrologic system. The combination, among those investigated, that yields a relationship most closely approximating the recorded output function in terms of the recorded input function and other arbitrary parameters is adopted as the best prediction equation.

In system analysis, the synthetic models in hydrology are dependent on the continuity equation of the form, $I = Q + \Delta S$, where I = total inflow, Q = total outflow and ΔS = change in internal storages for any given time interval. Any system like this, defined by the continuity of matter, is known as 'closed' system.

Through the general non-linear analysis, which started a few years ago, one can find out the relationships between partial inputs and partial outputs to be established independently, subject to some conditions of mathematical continuity and boundedness. It is not necessary to satisfy physical continuity conditions among the total input, total output and inner storage. When input and/or output represents only partial form of the total input or total output of the system, the system is called 'open'. Considering a hydrologic unit as an

open system one has obvious advantage in that it bypasses the need to evaluate component inputs and outputs.

Hydrologic system cannot be treated as analytic system because current mathematical knowledge is insufficient to evaluate the nonlinear kernels of the functions of series when multiple inversion is not possible due to complex input.

Physical simulation, for a hydrologic system, is not possible due to limited data. Ultimately digital simulation helps in this regard.

1.3 Simulation.

To simulate means to duplicate the essence of the system or activity without actually attaining reality itself. It is used to circumvent the difficulties of duplication of environment, of mathematical formulation, of lack of analytical solution techniques, or of experimental impossibilities.[2].

In hydrology simulation is used to correlate the observed hydrological behaviours to the factors which influence these and to predict the behaviour of watersheds where observed data are unavailable or incomplete. For this, large quantities of physical data on rainfall, evapotranspiration, streamflow, and other related variables are collected. Qualitative knowledge about the hydrological cycle is reasonably complete and interaction between major components such as rainfall intensity and infiltration rates can be logically explained. Still the

extension of qualitative knowledge to quantitative procedures is challenging. The land phase of the hydrological cycle contains complex interactions that are difficult to document from observed data, and the volume of data that must be analysed is formidable. Streamflow simulation attempts to develop algorithms of hydrological processes for quantitative calculations. In the present study hydrological reactions are assumed deterministic.

Since we are dealing with a physical system, a digitally simulated model deals with partial differential equations for rainfall, evapotranspiration, streamflow etc. This is too complex. Further, detailed and accurate data for soil moisture, overland flow etc. are not available in our country. Therefore, hydrologic basin models with lumped elements have been used with different levels of details.

1.3.1 Streamflow simulation models:

There are many models for streamflow simulation, few of which are described here. Three types of models are generally used these days. These are (a) Mathematical Models, (b) Retention Models and (c) Conceptual Models.

In the study of hydrology with mathematical modeling, run-off process can be analysed. Hydrometeorological characteristics which define the behaviour of catchments and the construction of mathematical models which approximately

reflect the process of the runoff are complementary. In modeling runoff some difficulties are encountered such as lack of basic data combined with considerable noise level and uncertainty of some links in the hydrologic process namely the characteristics of water movement in the drainage basin, its depth and the circumstances of its emergence on to the surface, followed by routing through the channel. To overcome all these, some hypotheses in models are used to match model with the natural data. The simplest of this kind is a model of snow-melt runoff on the surface of a mountain.

In Retention Model, a catchment is regarded as an inter-connected system of catchment units and channel units. Each catchment unit consists of a retention storage and a runoff storage. The retention storage does not meet the stream flow and is composed of capillary soil moisture, precipitation intercepted by vegetation, and some parts of the depression, ground water and channel storages. The runoff storage consists of the water that is likely to become streamflow, including over land flow, 'free' water moving through soil or litter, ground water and storage in minor channels. Informations of leakage, channel transmission losses are taken into account, if available. This model was originally suggested for analysing the effects of vegetation and soils on runoff volumes but it seems just as suitable for short term forecasting of floods due to rainfall [3].

The objective of a Conceptual Catchment Model is to simulate as accurately as possible the streamflow hydrograph under natural conditions and also to evaluate the modifications to natural flows resulting from man-made physical changes or management practices. Ideally, a conceptual catchment model should satisfy the following four conditions for maximum usefunless in river forecasting:

(1) It should represent the significant hydrological processes in a rational manner;

(2) It should contain the minimum number of parameters required for adequate representation of the processes;

(3) The values of the parameters should be measurable or be significantly correlated to easily measurable characteristics and

(4) The model should contain procedures for updating as new information becomes available, in a rational if not optimal manner.

There is still much to be learnt about the various phases of the hydrologic cycle and research is being carried out to increase the knowledge of them.

1.3.2 <u>Conceptual models</u>:

The basic philosophy of some of the well known conceptual models are presented below.

1. <u>Stanford Watershed Model (SWM)</u>:

This is the best known of the current conceptual models. A brief description only is given here and the fuller description is given in Chapter 2. The SWM simulates continuously the movement of water as it moves over, into and through the soil. It uses as input rainfall, snowmelt or both. Interception and storage losses must be satisfied initially. A portion of the runoff comes over the impervious surface and joins the streamflow and the rest passes over the pervious surface and is subject to the soil moisture conditions. Infiltration capacities vary from watershed to watershed. Detention storage, overland flow and interflow are due to the accumulation of water on the upper zone. Water moves from upper zone to lower zone and ultimately joins the ground water storage. Water stored in the soil moisture zone is called lower zone storage. Lake evaporation from class A pan records is assumed to be potential evapotranspiration. Evapotranspiration is assumed to take place from interception storage, upper zone, lower zone and ground water storage but at different rates. Ground water runoff, interfow and surface runoff are routed seperately and combined to produce outflow hydrograph. Hydrological processes are represented mathematically and the parameters involved in these mathematical quantities are obtained by the digital computer.

2. <u>The Utah State Simulation Model:</u>

This simulation model has been developed by the Utah State University. The computer needed for its solution is an analog computer. Its objectives are (i) the development of improved relations for describing the various hydrological processes and inter-connecting link between these processes, and (ii) the development of an analog computer having a high degree of flexibility and capability for the solution of hydrological and related problems.

The hydrologic balance of this model is given by,

$$P = I + \Delta M_s + SRO + \Delta G_s + GWO + ET \pm \Delta S_s$$

where,

P = Precipitation,

I = Interception loss,

ΔM_s = Change in soil moisture storage,

SRO = Surface run-off,

ΔG_s = Change in ground water storage,

GWO = Ground water run-off,

ET = Evapotranspiration, and

ΔS_s = Change in surface storage.

Interception loss is a function of type and density of cover and precipitation. SRO is the excess of precipitation over the infiltration rate. Soil moisture storage is a function of infiltration, evapotranspiration, interflow and percolation

to ground water storage. The relation of actual to potential evapotranspiration rate is assumed to be a function of soil moisture deficiency. Percolation of ground water is dependent on soil moisture storage. Ground water runoff is a function of ground water storage. The increments of surface runoff, inter flow and ground water are routed seperately through different amount of storage.

3. The Agricultural Research Service Model:

This model, responsible for agricultural research in the U.S., is based on infiltration theory approach. In this model first the depression storage on the surface must be satisfied. An assumption is made that some impeding stratum of the soil acts as a control on saturated flow. Therefore, the infiltration capacity (f) of a surface soil approaches the low constant seepage rate (f_c) of the impeding stratum as the overlying storage (S) is exhausted by infiltration volumes (F). The equation is as follows:

$$f = a\,(S - F)^{1.4} + f_c$$

where, a = percentage of area occupied by plant crowns, because plant roots connect large pores and provide continuous channel.

For this model, soil data are needed which permit determinations of soil porosities and occurrence of impeding strata.

Soils are grouped in accordance with their constant rate of infiltration after prolonged wetting. This constant rate is assumed as the seepage rate through the impeding strata. Porosities are classified as (i) pores (h), free water drainable by gravity, and (ii) pores, available water capacity (AWC), drainable by evapotranspiration. Recovery of available storage, by this means, is at the rate of seepage (f_c) to the extent of freely drainable porosity. Further recovery of available storage capacity between the days of rain is at the rate of evapotranspiration (ET) to the extent of plant available water (AWC). Different values of a's, plant root coefficients, are prepared relative to various land use and treatments. Potential ET is estimated from pan-evaporation with a seasonal consumptive use coefficient applied to obtain the actual evapotranspiration. Water in excess of infiltration and surface depression storage is assumed available for run-off and is routed by successive routing techniques to reproduce the outflow hydrograph.

4. <u>The Columbia River Basin Model</u>:

The input to this model is weighted rainfall plus computed snowmelt on a daily basis. This daily input is distributed into specific time period (3,6 or 12 hours). The total runoff is calculated by multiplying rainfall, snowmelt or both by a percent coefficient which is a function of soil

moisture index. The soil moisture index at the end of a period is the soil moisture index at the beginning plus precipitation minus total run-off minus evapotranspiration for the same period. Evapotranspiration on rainy day is less and is obtained by multiplying the daily value by a coefficient. The percent of the total runoff contribution to base flow is computed as a function of a base flow infiltration index. The remaining runoff is separated into surface and subsurface components as a function of the total input rate. Components of surface, subsurface and baseflow runoff are routed separately, using a successive reservoir routing technique. It is also possible in this model to introduce rule curves for operation of reservoirs and/or to specify release schedules for all or selected reservoirs.

Studying all the above models it is observed that the Stanford Watershed Model is the best suited in this study, considering the availability of data. The Kentucky version of the Stanford Watershed Model known as Kentucky Watershed Model (KWM) was available with us for analysis.

KWM has a number of parameters. Estimation of these parameters is very time consuming. 'A self calibrating model' known as OPSET is available for finding the best fit of values for the parameters so that simulated flow matches the recorded flow. This model uses hourly rainfall data, daily streamflow

data and yearly, daily or 10-daily average evaporation data besides several other types of data.

In India, there are nearly 400 self recording rain gauge stations. The data from these stations are yet to be used in detailed hydrologic modeling of basins. It seems possible to use KWM in order to model basins with hourly rainfall data. Hence, it is proposed to implement the OPSET program developed by the University of Kentucky and available with us and use it, if possible, to model a basin for which data are available.

1.4 Statement of the Problem:

The objectives of the study are

(1) to implement the OPSET programme for estimation of parameters of the KWM using the test data given in the original report [4], and

(2) to estimatethe parameters for a basin in India with the requisite data.

1.5 Scope of the Study:

(1) The implementation of OPSET on IBM 7044 and IBM 370/155 computer systems is done using the set of available test data.

(2) **Estimation** of parameter values for a basin in India is done on the basis of available data.

Within the limitations of time, computer facilities, money and data availability, parameters are determined only for 2 years for the Indian basin.

CHAPTER II

DETAILS OF OPSET PROGRAM

2.1 Kentucky Watershed Model:

2.1.1 General Description:

The Kentucky Watershed Model (KWM) is the translated, revised and expanded version of the Stanford Watershed Model. Originally, the Stanford Watershed Model was written in a digital computer language SUBALGOL. James [5,6,7] translated it into FORTRAN IV and modified it. This version is known as KWM. As the basic logic of SWM and KWM are same, the description of Stanford Watershed Model is given here.

SWM is a systematic mathematical representation of the hydrologic processes in the hydrologic cycle. Mathematical formulations in the model are empirical for some of the processes.

In this model the major input data are evapotranspiration and rainfall. If snow is a significant part of precipitation, then snowfall data should also be given as input data. In addition, several other input parameters and control arrays must be selected based on Watershed behaviour, characteristics and data availability. The details of input parameters are given by James [5].

Output consists of synthetic streamflow, overland flow, interflow, baseflow, stream evapotranspiration (net and potential) and ground water storage. These hydrologic quantities can be obtained daily, monthly or annually as appropriate for use by the researcher.

2.1.2 Flow Chart of KWM:

A schematic flow chart of KWM is given in Fig. 2. In the above mentioned figure the boxes represent classifications of moisture storage. Arrows are the processes through which moisture moves from one type of storage to another type of storage. The vertical straight line from precipitation to subsurface flow with arrow downwards represents the flow of water through the porous media due to gravity. When moisture cannot move downward due to some restrictions, such as low permeability, moisture starts accumulating in the higher boxes. Water moves laterally and joins the stream when storage capacities of these boxes are exceeded. Ultimately, it goes out of the watershed. Vertical straight line with arrow upward indicates the withdrawal of water from all levels of storages due to radiation energy, and moisture needs of vegetation.

The path taken by incoming moisture is determined by the antecedent moisture storage, the magnitude of the assigned parameter values, the entry rate and the season of the year.

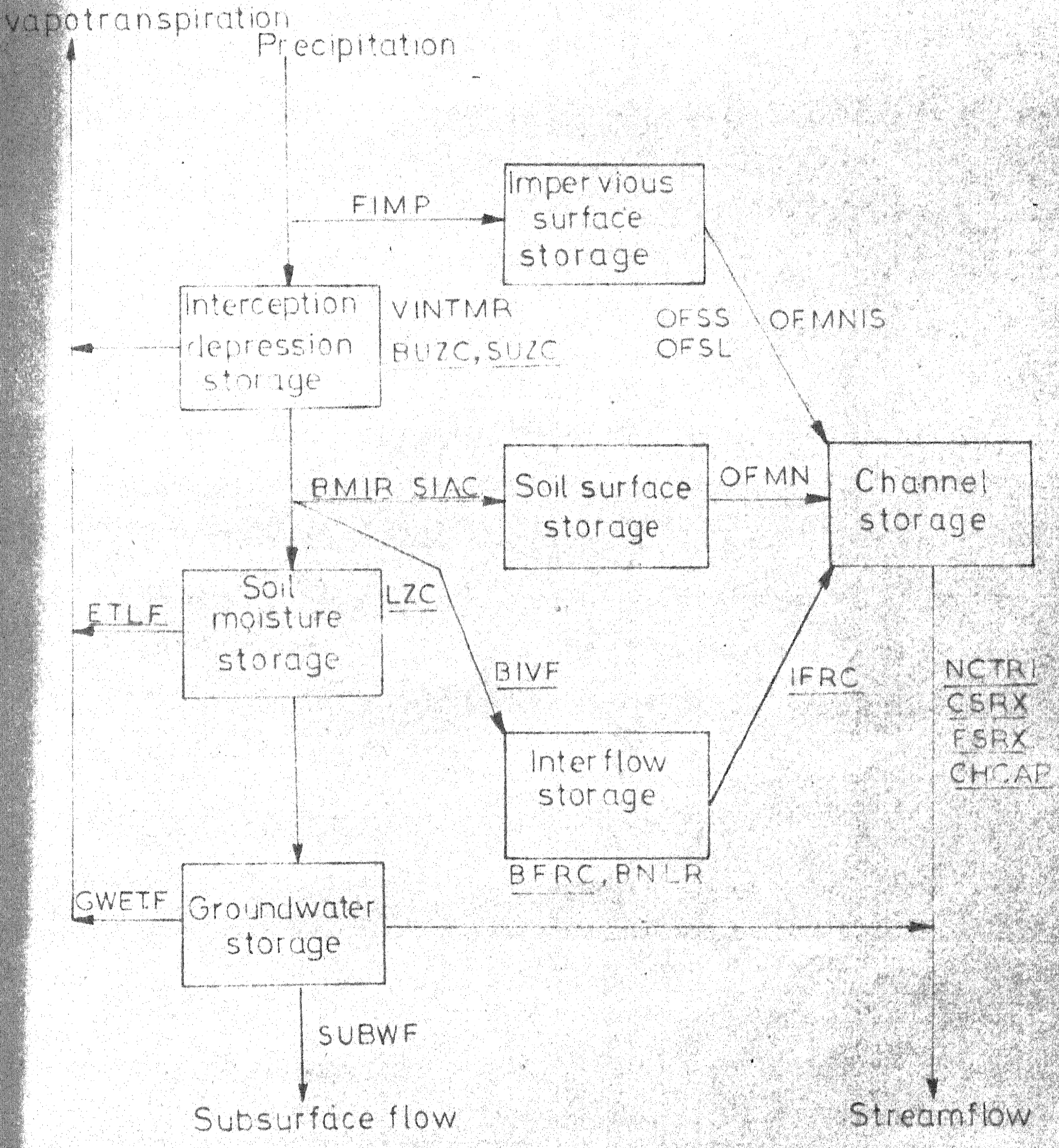


FIG.2 SCHEMATIC FLOW CHART OF KWM

The quantities appearing along the flow lines are the parameters which control the flow of moisture along those paths.

2.1.3 Input Data to KWM:

The input data required by SWM or Fortran KWM are divided into 6 groups as follows:

1. Data to specify the desired program options and required specific output.
2. Data to initialize the watershed soil moisture storage condition.
3. Data to establish climatological events.
4. Time-area histogram for watershed under study.
5. Data to assign values to the watershed parameters,
6. Recorded streamflow to compare with the synthesized flow.

2.2 OPSET:

2.2.1 Definition of OPSET and Purpose of KWM:

OPSET is a self calibrating model. It is called OPSET because of its objective to estimate the OPtimum SET of parameter values. Input parameters are those which can be directly measured by the user. Other parameters are repeatedly adjusted by OPSET to match the synthetic hydrograph with observed hydrograph until no further adjustment is possible. Optimum set of parameters are obtained from OPSET for different water year

for a watershed and then averaged. They can be used in KWM. KWM, in order to synthesize streamflows, uses these parameter values with much larger number of control options. A schematic diagram of parametric optimization procedure followed by OPSET program is shown in Fig. 3.

2.2.2 Parameters Estimated by OPSET:

There are altogether 13 parameters to be determined by OPSET which are classified as follows. These parameters are underlined in Fig. 2.

Recession Constants:

1. IFRC - Interflow Recession Constant
2. BFRC - Baseflow Recession Constant

Land Phase Parameters:

(a) Runoff Volume Parameters:

LZC - Lower Zone Storage Capacity,

BMIR - Basic Maximum Infiltration Rate Within Watershed,

SUZC - Seasonal Upper Zone Storage Capacity Factor,

ETLF - Evapotranspiration Loss Factor,

BUZC - Basic Upper Zone Storage Capacity Factor,

SIAC - Seasonal Infiltration Adjustment Factor.

(b) Surface Volume Parameters:

BIVF - Basic Interflow Volume Factor

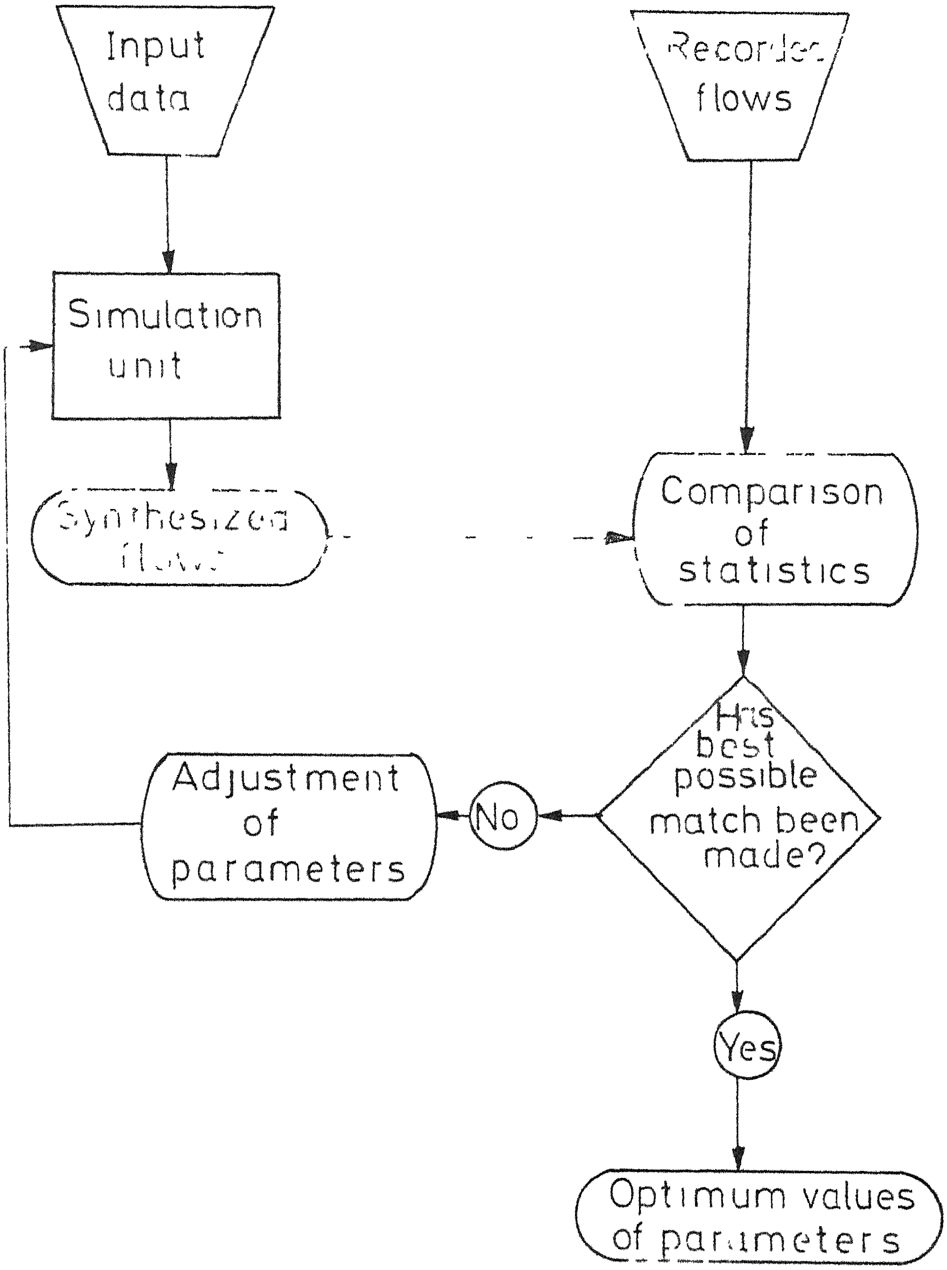


FIG. 3 SCHEMATIC DIAGRAM OF PARAMETER OPTIMIZATION PROCEDURE

Channel Routing Parameters:

1. NCTRI - Number of Current Time Routing Increments,
2. CSRX - Channel Storage Routing Index,
3. FSRX - Flood Plain Storage Routing Index,
4. CHCAP - Channel Capacity - Indexed to Basin Outlet.

2.2.3 Physical Significance of Parameters:

Over a real watershed, the hydrologic processes are continually going on at rates varying with time and location. The movement of moisture at any point is in response to acting forces (gravity) counteracted by the resistance to moisture movement along a given flow path. The resultant moisture moves in low resistance zone. Physical factors governing the saturated and unsaturated flows include the size and shape of the particles, the porosity, orientation, and the moisture content of the area, viscosity and surface tension of water and information on how these factors vary over time and space. In this model lumped estimation process has been used. Option is there in SWM to divide the whole area into a number of segments. The estimate should also be lumped over a finite interval of time (15 mins. in SWM). They also can be lumped to a group of related hydrologic processes such as interception storage is added to depression storage in the SWM. Baseflow recession constants represent the cumulative effect of moisture movement along a large number of routes. Lumped

estimates imply that watershed parameters somehow aggregate the effects over space and time. Best values are those which give the synthesized flow close to the recorded flow. But this depends on the data measurement error, size of the area and length of time represented etc. One point is very important that the parameters which are best in 15 minutes time increments will not be the best in 60 minutes time increments [8].

2.2.4 Parameter Estimation Criteria:

There are two criteria to choose the parameters which are to be estimated by the OPSET program. First, the parameters should be difficult to measure directly. Parameters like drainage area should not be estimated by matching synthetic flow with the recorded flow as it is easy to measure this to a satisfactory degree of accuracy. Second, the simulated flow sequences should be sensitive to the parameters. Considering the above two criteria the thirteen parameters mentioned before were chosen.

2.3 Parameter Estimation:

The procedure followed by OPSET program to estimate the parameters is outlined below.

2.3.1 Recession Constants (BFRC and IFRC):

Traditional graphical techniques to find out BFRC (base flow recession constant) and IFRC (inter flow recession constant)

are time consuming. The recession sequence is selected by the subroutine RECESS. Maximum length of each sequence is 50 days and for each station year upto 20 flow sequences are selected. Minimum number of days needed to estimate a single recession constant is 2 and for 2 constants 4 days are needed. Longer sequences give better results. As recessions from very small flow do not give good results a criterion is used that the second day flow should be either greater than 10 cfs or greater than 0.4 x AREA (where AREA is the watershed area in sq. miles). Second day is the day after peak or the first day whose flow is actually used to find recession constants. The recession sequence is terminated by a flow rise exceeding 0.1 x SQRT (AREA) cfs. After finding out the recession sequences through the subroutine RECESS the subroutine SET2RC and SET1RC are used to find the values of IFRC and BFRC.

Subroutine SET2RC is called first to estimate the two recession constants IFRC and BFRC, If the sequence starts with a relatively low flow and flat recession then it is assumed that only base flow is present and subroutine SET1RC is used. Here BFRC is found. If the value of BFRC does not come up between 0.6 and 1.2 the entire sequence is discarded.

2.3.2 Runoff Volume Parameters (LZC, BMIR, SUZC, ETLF, BUZC,SIAC):

In order of decreasing sensitivity these parameters are LZC, BMIR, SUZC, ETLF, BUZC and SIAC. The subroutine SETFVP

adjusts the values of five flow volume parameters LZC, SUZC, ETLF, BUZC and SIAC during the process of estimating the best set of values for the six flow volume parameters. In order to see how and to what degree each of these parameters affects runoff, a sentivity study was made with the data for Elkhorn Creek, Frankfort, Kentucky, USA, for the year 1964. First of all a best set of parameter values were selected by trial and error. Then for each of six parameters 2 computer runs were made by varying that parameter keeping others constants. Each parameter had effect on simulated flow and differed with the changes of type of flow and changes in time of the year. BMIR is adjusted through the subroutine SETBMI and other five through SETFVP. These two subroutinesfunction as unit and adjusts the six volume parameters simultaneously.

First of all, trial values are taken for these parameters and a year of streamflow is simulated. Then each parameter is adjusted by its adjustment rule. The new set of six values is used to simulate another year of streamflows, and this process continues until the simulated flowshave smaller SSQM as computed by subroutine SETFDI. Recorded and simulated flows cannot match perfectly due to data and modeling difficulties.

Runoff volume parameters are defined as follows:

1. BUZC:

It is an index for estimating the capacity of the soil surface (upper zone) to store water in interception and depression storage. Wetter the underlying layer more will be the amount of water stored in this layer.

2. SUZC:

It is an index for estimating soil surface moisture storage capacity. Seasonal storage capacity changes due to summer vegetation and cultivation is taken care of by SUZC. BUZC and SUZC are used to compute the upper soil zone nominal storage capacity (UZC) by the following equation.

$$UZC = SUZC\ (AEX90) + BUZC\ (e^{-2.7} \times \frac{LZS}{LZC})$$

where,

$AEX90$ = Antecedent evaporation index ($K = 0.90$),

$\frac{LZS}{LZC}$ = An index of the moisture content of the underlying soil,

e = Natural logarithm base.

3. LZC:

It is the soil-moisture storage capacity index which approximately equals the volume capacity of the soil to hold water. Decreasing LZC will be reducing the ability of soil to hold water and thus increasing the synthesized flow and the reverse when the value of LZC increases. Delayed infiltration

or percolation happens from the upper zone to the ground water and lower zone storages when UZS/UZC exceeds the value of LZS/LZC (Ref. Figs. 4 and 5).

4. ETLF:

ETLF is an index used to estimate the maximum rate of evapotranspiration which could occur within the watershed under current conditions of soil moisture content. This maximum rate is then used to estimate current actual evapotranspiration in the manner depicted in Fig. 6. More trees in a watershed means higher value of ETLF and less simulated flows (Ref. Fig. 6).

5. SIAC:

It is an evaporation-infiltration factor relating infiltration rates to evaporation rates to account for more rapid infiltration during warmer period. Higher the value of SIAC less is the runoff.

6. BMIR:

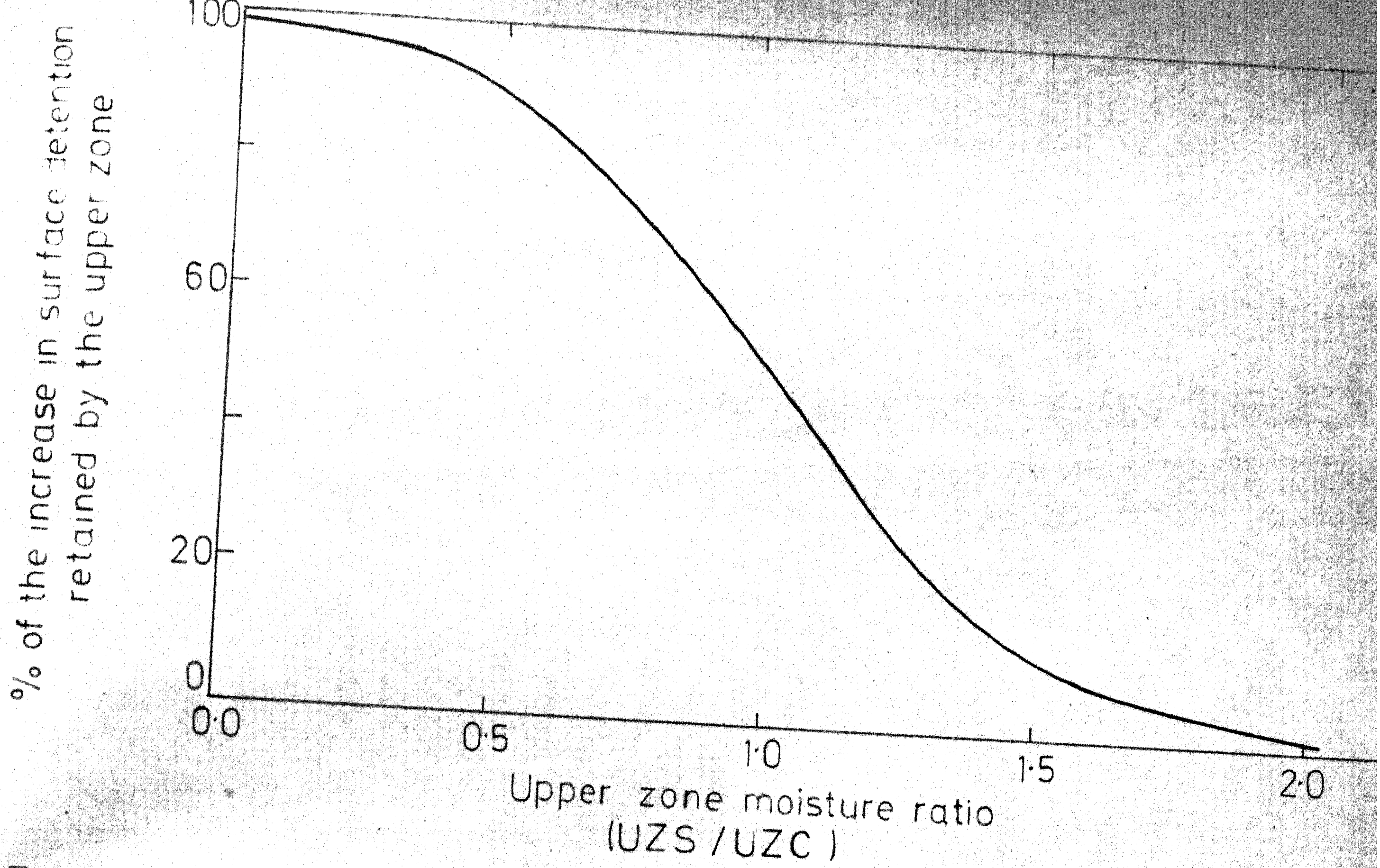
It is the basic infiltration index used to control the rate of infiltration. Infiltration rates vary from point to point in a watershed and most runoff will be from points with smaller rates. A cumulative frequency distribution is used in SWM, varying linearly from zero to a maximum value (Ref. Fig. 7).

The equations relating maximum capacity to infiltration rates, applicable at any particular point in time (CMIR), are given by,

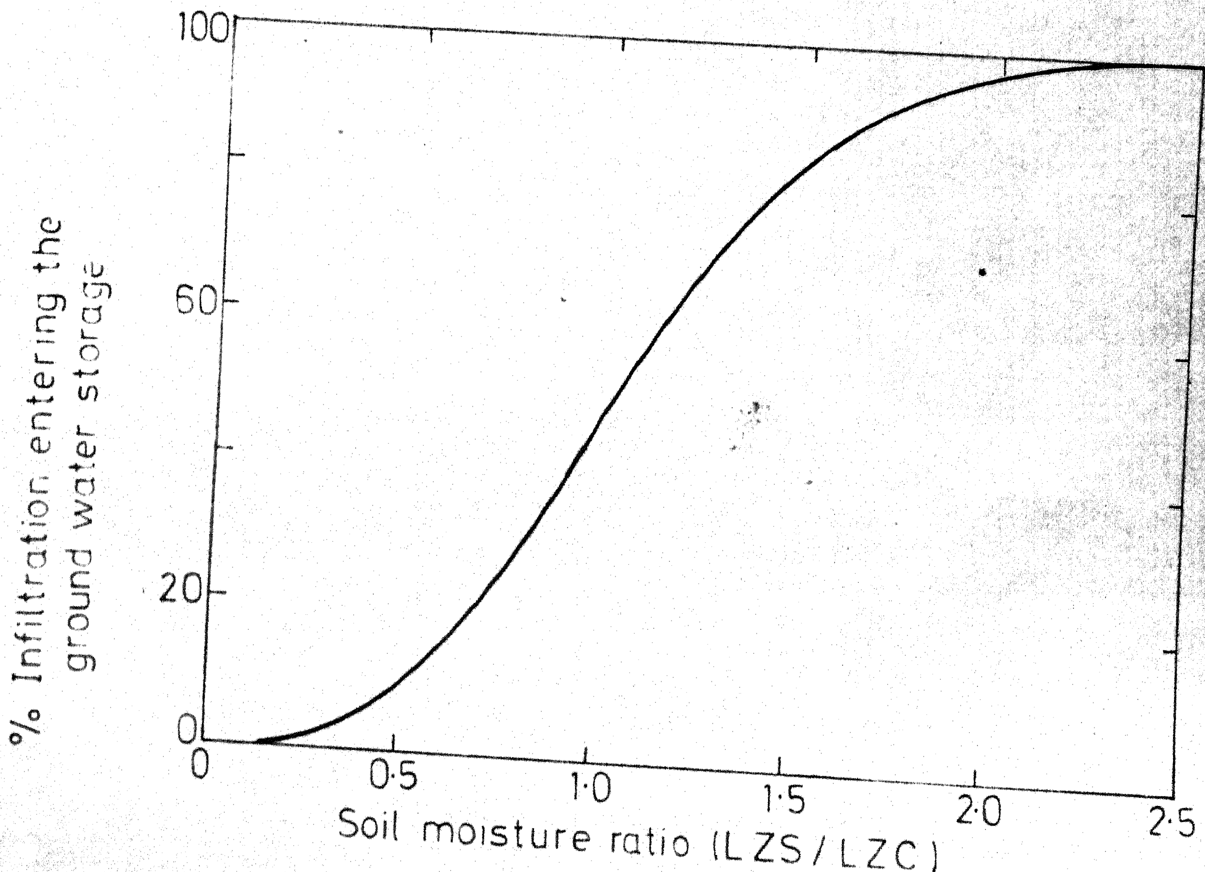
$$\text{CMIR} = \frac{\text{Constant x SIAM x BMIR}}{\text{Function (LZS/LZC)}}$$

$$\text{SIAM} = \text{Function (SIAC)}$$

$$\text{CIVM} = \text{BIVF x Function (LZS/LZC)}$$



FIG·4 MODEL FOR ESTIMATING THE UPPER ZONE STORAGE COMPONENT OF SURFACE DETENTION



FIG·5 MODEL FOR ESTIMATING INFILTRATION ENTERING GROUNDWATER STORAGE

Maximum rate=ETLF*LZS/LZC

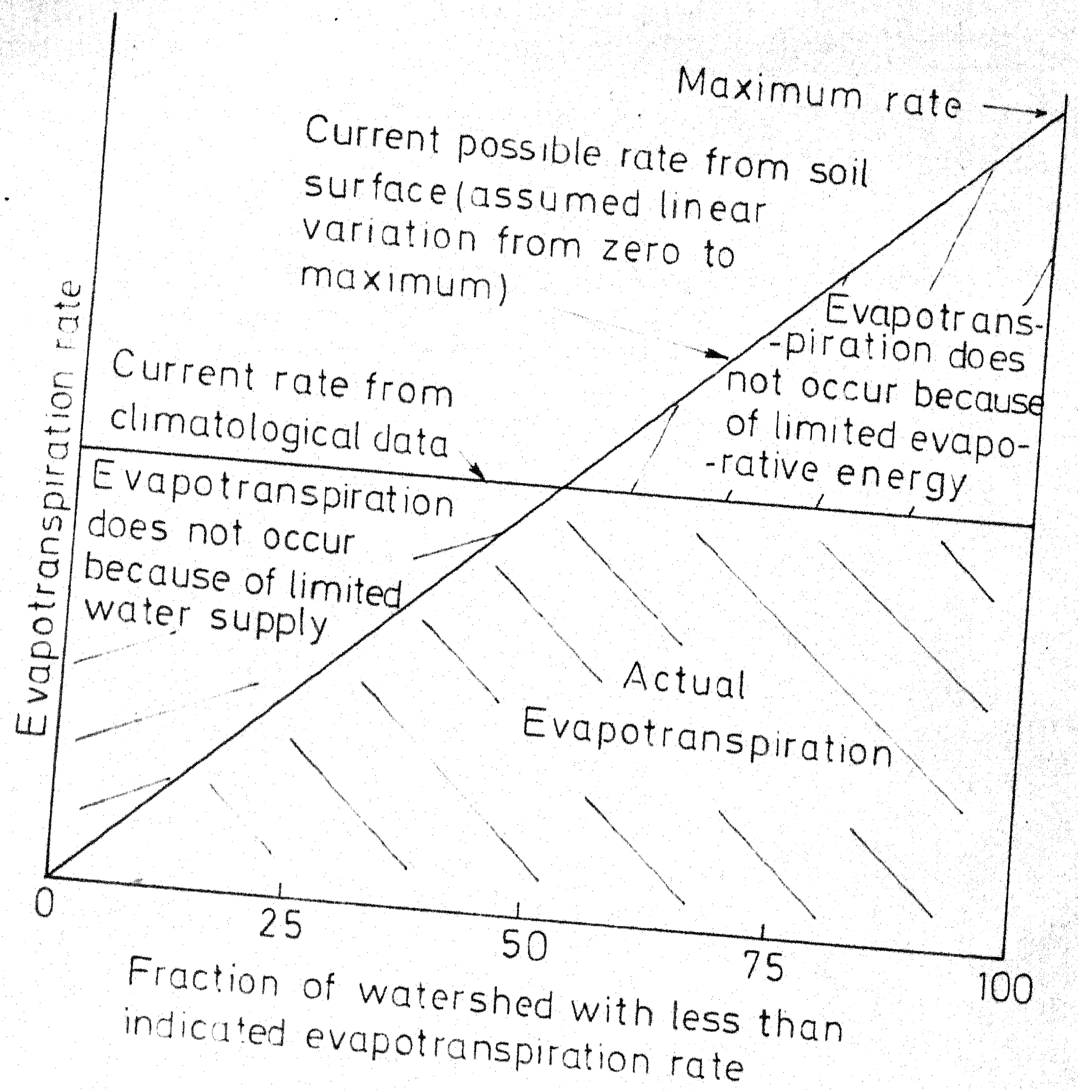


FIG.6 MODEL FOR ESTIMATING ACTUAL EVAPOTRANSPIRATION

$$\text{CMIR} = \frac{\text{CONSTANT}*\text{SIAM}*\text{BMIR}}{\text{function (LZS/LZC)}}$$

$$\text{SIAM} = \text{function (SIAC)}$$

$$\text{CIVM} = \text{BIVF}*\text{function (LZS/LZC)}$$

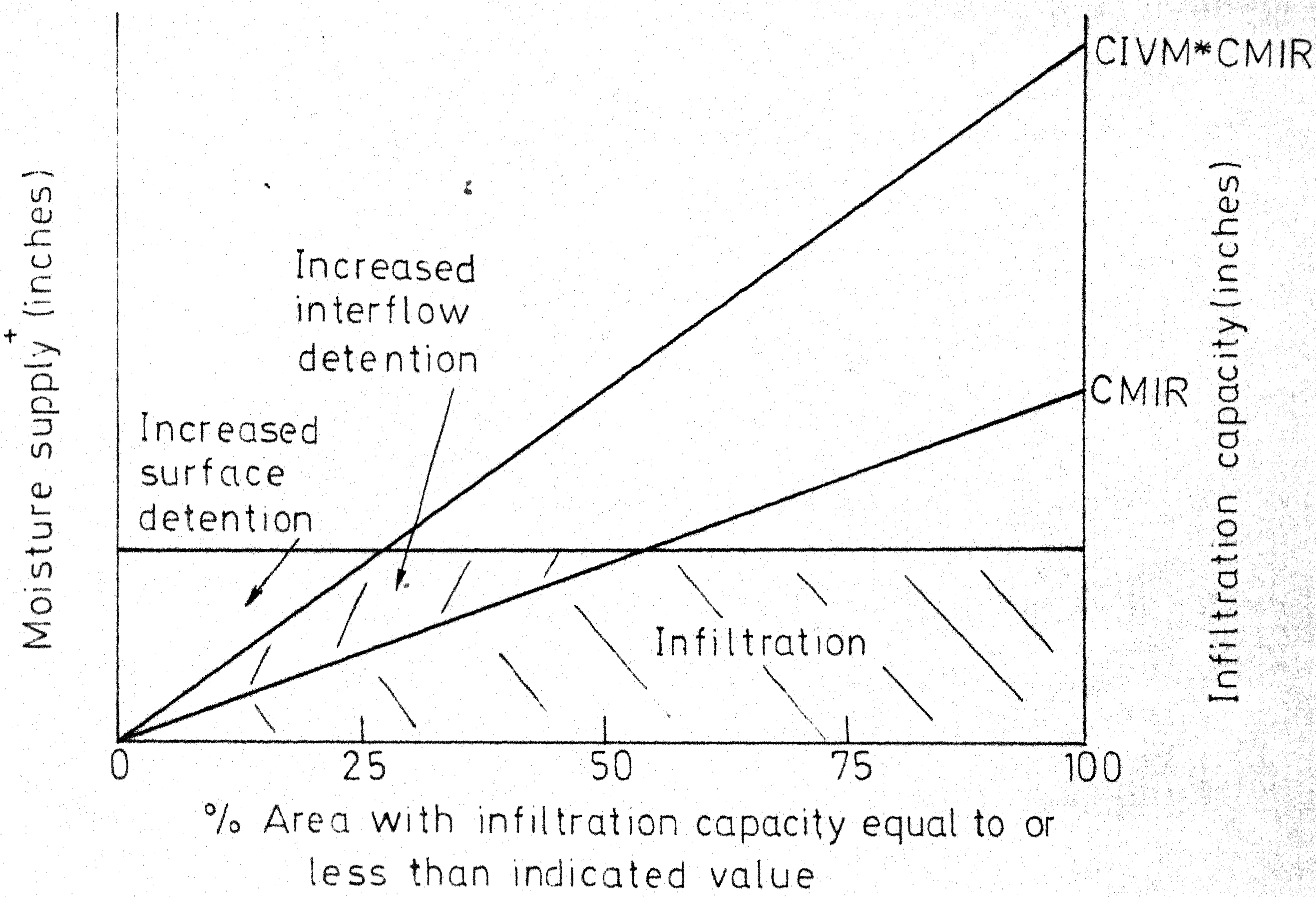


FIG. 7 MODEL FOR ESTIMATING INFILTRATION CAPACITY

+ Rainfall passing through the upper zone plus holdover direct runoff

Increase in the value of BMIR reduces runoff during storm periods and later on increases runoff due to baseflow.

2.3.3 Surface Volume Parameter (BIVF):

It is an index controlling the time distribution and quantities of moisture entering the interflow. Increase in BIVF means more interflow by increasing the volume of CIVM. BIVF enters the streamflow simulation through the equation,

$$CIVM = BIVF \times 2^{(LZS/LZC)} \quad \text{(Ref. Fig. 7)}$$

In order to check negative interflow CIVM must be ≥ 1. It is determined by the subroutine SETBIV.

2.3.4 Channel Routing Parameters (CSRX, FSRX, NCTRI, CHCAP):

The subroutine SETHRP estimates single best values for NCTRI and SRX for each of the 5 hydrographs (maximum 5) specified in the input data. Hydrograph NCTRI values are averaged in it to have single best value of NCTRI. The storage routing uses the equation,

$$O_2 = \bar{I} - SRX\ (\bar{I} - O_1)$$

where,

O_2 = routed outflow at the end of the time interval,

$\bar{I}$ = average inflow during the time interval,

O_1 = outflow at the beginning of the time interval,

SRX = storage routing index.

SRX for low flows is denoted by CSRX and SRX for flood flows is denoted by FSRX.

SETSRP estimates two channel routing parameters CSRX, FSRX. When the synthesized streamflow is less than one-half of CHCAP, CSRX is used for routing. If the synthesized flow exceeds twice CHCAP, FSRX is used. When the synthesized flow is in between these two SRX is interpolated from the equation,

$$SRX = CSRX + (FSRX - CSRX) \times \left(\frac{Q-0.5\ CHCAP}{1.5\ CHCAP} \right)^3$$

where,

Q is the synthesized streamflow.

2.4 Parameters Directly Estimated from the Watershed Characteristics:

1. AREA : Total area of the watershed in sq. miles,
2. FIMP : Fraction of watershed which is impervious and contributes its runoff directly into a stream.
3. FWTR : Fraction of total watershed covered by water surfaces,
4. VINTMR: Watershed interception volume storage capacity.

It is dependent upon the type and density of vegetative cover. A table to choose VINTMR is given below:

Table 1: Interception Values for Various Types of Cover. [4]

Watershed Cover	VINTMR (in)
Grass land	0.10
Moderate Forest cover	0.15
Heavy Forest cover	0.20

5. GWETF : It is a factor which when multiplied by the current rate of potential evaporation times the current ground water moisture storage gives an estimate of the current rate at which phreatophytes or swamp vegetation are drawing water from below the water table. For most of the basins this value is recommended to be zero [4].

6. SUBWF : Fraction of the moisture entering ground water storage which leaves the basin through sub-surface flow not measured by the stream gauge. Generally its value is zero.

7. OFSS : Average slope (in ft/ft) of the overland flow surfaces perpendicular to the receiving channel. Mean value is taken from randomly selected group of points on a topographic map.

To find out the discharge from the over land flow by Chazy-Manning formula this OFSS is used in the following equation:

$$q = \frac{1.486}{n} (y^{5/3}) (S^{1/2})$$

where,

q = discharge in cfs/ft.

y = depth of flow in ft.

S = slope of the surface in ft/ft (OFSS)

8. OFSL : Mean overland flow length in ft.
It is the average distance that surface runoff in the watershed travels before reaching a channel. It is estimated as the reciprocal of twice the drainage density in sq.miles.

9. OFMN : Manning's roughness coefficient for overland flow on soil surfaces.

10. OFMNIS: Manning's roughness coefficient for overland flow over impervious surfaces.

11. CHCAP : Channel capacity - indexed to the outlet of basin: CHCAP may be estimated from hydraulic analysis of the profile and cross-section of the stream channel.

12. DIV : This is the daily flowdiversion in cfs. Diversions into the streams are considered as positive.

2.5 Earlier Studies Using OPSET:

The original work on the development of Watershed Model started in 1959 at Stanford University in USA. Its name was given as Stanford Watershed Model (SWM). This model was developed through the versions of I, II, III and IV and was programmed for the digital computer in SUBALGOL language. D.L. James translated the model III into FORTRAN (G-Level) and simultaneously incorporated most of the features of model IV. This model was named as Kentucky Watershed Model (KWM). The

University of Kentucky in the year 1970 developed a self calibrating model named as OPSET. Then this model was tested in 20 watersheds most of which are rural. Liou [8] and Ross [4] gave **full** reports of the application of this OPSET models in the U.S.A.

CHAPTER III

IMPLEMENTATION OF OPSET PROGRAM

3.1 Important Characteristics of the Program:

Important characteristics of the OPSET program are described below:

3.1.1 Program Size and Memory:

OPSET is a very lengthy program. In all, about 2400 cards are needed to be punched (excluding data). Available core memory in IBM 7044 at IIT Kanpur is less than 32 K words (1 word = 6 bytes in IBM 7044 system). This memory is not sufficient for the OPSET program. On IBM 7044 two compilers are available viz. (i) WATFOR, (ii) FORTRAN. WATFOR compiler gives an extensive diagnostic report but execution is slow. Due to memory problem, and even for debugging purpose, the whole program could not be run at a time. Main program and each subroutine had to be fed separately for correcting the syntax errors. This did not solve the purpose. FORTRAN compiler ignores the undefined variables and some erroneous part of the program.

All these difficulties are overcome through the IBM 370/155 computer system at IIT Madras. Here WATFIV compiler which has a memory upto 512K bytes, has been used to

debug the program. The total memory requirement with one set of data is 250 K (bytes)(1 word on IBM 370/155 system equals 4 bytes).

3.1.2 Computer Time:

In IBM 370/155 system through WATFIV compiler with one year's data and all the options, computer time needed is 15 minutes (compilation and execution). This implies that IBM 7044 will take more than one hour to do the same job, because IBM 370/155 compiles and executes respectively eight and four times faster compared to IBM 7044/1401 system at IIT/Kanpur.

3.1.3 TRIPS:

The program is divided into three portions. In execution of the first portion 6 variables are taken into account. In the execution of the second portion other variables are considered. In the final step all the variables are taken together to give final synthesis. Execution ~~of each~~ of these portions is called a TRIP. First TRIP gives the optimized values of LZC, BMIR, SUZC, ETLF, BUZC and SIAC. In addition to these values, two other parameters BIVF and LZS are also obtained. The second TRIP starts working when the above values are optimized. In this TRIP the other six parameters CSRX, FSRX, NCTRI, CHCX, IFRC, BFRC are optimized. Here the parameter values of the first TRIP remains unaltered. In the third TRIP all the parameter values taken together give the final run with the simulated flow.

3.1.4 Language:

The OPSET program is written in FORTRAN language. In this program one subroutine READ is used to read data in free format. But this subroutine is not readily available with us. READ subroutine is therefore replaced by the formated READ statements.

3.2 Modifications:

1. Water Year.

In the United States the water year is counted from the 1st October of the one year to the 30th September of the next year. In this study it is taken from the month of June and is modified accordingly.

2. Evaporation Estimates:

In the test data of the OPSET program the evaporation is taken as the total evaporation in a year in inches and through the subroutine EVPDAY the daily values were calculated. In the present study the 10 daily average values of evaporation are used.

3. Flood Peaks:

The flood peaks data for the watershed, used in the present work, are not available. These values are, hence, interpolated from the stream flow data.

3.3 Addition and Alterations:

To take care of the nonavailability of some data prescribed for the program and to work with the program in a different computer system, some necessary changes have been made. These are described below:

1. All the evaporation data available in the study are in mm, but the OPSET program uses them in inches. Through the following statements the evaporation data in mm are changed to inches,

```
990  DPET (KRD)  =  0.03937 *DPET (KRD)
991  DPET (KRD)  =  0.03937 *DPET (KRD)
```

2. In the original program the following statements were used to read the recorded stream flow for one year.

```
118  DAY  =  274
119  CALL REAL (DRSF (DAY))
     CALL DAYNXT (DAY,DPY)
     IF (DAY.NE.274) GO TO 119
```

It is necessary to change the above statements as in the present case the first day of a water year is the 152 nd day of the calender year and not the 274th day as stated in the program. The following statements are, therefore, introduced.

```
118  DAY  =  274
     READ 1000, (DUM(J),J = 1, DPY)
     PRINT 1000, (DUM(J), J = 1, DPY)
     ISEQ  =  1
```

```
119  DRSF (DAY) =  DUM (ISEQ)
     ISEQ  =  ISEQ + 1
1000 FORMAT (13F6.1)
     CALL DAYNXT (DAY,DPY)
     IF (DAY,NE.(396-DPY)) GO TO 119
```

Here one dummy array DUM (J) is introduced. June 1 data is read as October 1 data. But these two dates differ in a year by 122 days, so the last line in the above statement 274 was replaced by 396-DPY.

3. The following statements are given in the main program of OPSET.

```
      DO 126 KRD  =  1, NSGRD
      CALL READ (ISGRD)
  126 CALL READ (DRSGP (ISGRD))
C     READ RECORDING RAIN GAGE HOURLY TOTALS
  127 CALL READ (IWBG, YEAR, MONTH, DATE, CN)
C     PUNCH NO NUMBERS AFTER CN ON YEAR.EQ.98 CARD
      IF (YEAR.GE.98) GO TO 130
      HRF = 12* (CN-1) + 1
      HRL = 12* (CN-1) + 12
      DAY = MEDCY (MONTH) + DATE
      DO 128 HOUR = HRF, HRL
  128 CALL READ (DRHP (DAY, HOUR))
      IF (DPY.NE.366.OR.MONTH.NE.2.OR.DATE.NE.29)GO TO 127
```

he above statements are changed to the following form for easons mentioned above.

```
          DO 126 KRD = 1, NSGRD
          READ 500, ISGRD
          READ 103, DRSGP (ISGRD)
      126 DRSGP (ISGRD) = 0.03937* DRSGP (ISGRD)
C     READ RECORDING RAIN GAGE HOURLY TOTALS
      127 READ 500, IWBG, YEAR, MONTH, DATE, CN
C     PUNCH NO NUMBERS AFTER CN ON YEAR.EQ.98 CARD
          IF (YEAR.GT.98) GO TO 130
          HRF = 12* (CN-1) + 1
          HRL = 12* (CN-1) + 12
          DAY = MEDCY (MONTH) + DATE + 122
          IF (DAY.GT.DPY) DAY = DAY-DPY
          DO 2000 IJK = 1,12
          IF (DAY.GT.MEDCY (IJK)) GO TO 2000
          MONTH = IJK - 1
          GO TO 2050
     2000 CONTINUE
     2050 CONTINUE
          READ 1003, (DRHP (DAY,HOUR),HOUR = HRF,HRL)
          DO 1291 HOUR = HRF, HRL
     1291 DRHP (DAY, HOUR) = 0.03937* DRHP (DAY,HOUR)
     1003 FORMAT (12F 5.2)
          IF (DPY.NE.366.OR.MONTH.NE.2.OR.DATE.NE.29) GO TO 127
          DO 129 HOUR = HRF, HRL
```

Other alterations are mainly the changes in the FORMAT statements and corrections of some printing errors in the OPSET program. These are not mentioned here.

3.4 Time Spent on Collecting the Data and Implementing OPSET:

The collection of relevant data, required for this program, constitute a large portion of the present work. Collection of data was started first in September 1974 and ultimately all the data could be collected from different places by the end of June 1975. Punching and correcting of the program started long before and ultimately in July 1975 the program was in perfect working condition. Only after that the work on the basic objective i.e. to use OPSET for quantifying an Indian watershed, could be started. The work has been finally completed in October, 1975.

3.5 Factors Affecting the Efficiency of the Program:

1. Due to heterogeneous properties in the large watersheds it is very difficult to correlate the model parameters with watershed character. Watershed should be small enough to be homogeneous to minimise this difficulty.

2. The basin area should not be very large.

3. One run of OPSET program takes a large amount of computer time and the computer expense is high. So for economic reasons it is desirable to use OPSET for as few years as possible.

4. Two factors cause the variation of the parameter value for different water years. These are (i) differences in the pattern of deviation from year to year between gauge and watershed rainfalls and (ii) the differences in the pattern of the stream flows among the years.

CHAPTER IV

MODELING OF THE INDIAN BASIN AND THE RESULTS

4.1 Description of the Basin.

The basin is bordered by two canals on two sides (Fig. 8). The whole area of the basin is more or less flat. The climate is temperate during hot summer months from May to September. Thereafter air becomes drier and cooler every day. Hoarfrost is common in January and February. For few nights in the year the ground temperature falls below 0°C. Average mean monthly maximum and minimum temperatures vary between 60°F to 110°F and 35°F to 80°F respectively. Northeast part of the area receives more than 50 inches (1270 mm) of rainfall annually and the southwest part receives between 15 inches to 20 inches (381 mm to 508 mm). This area has been formed of alluvial deposits brought by the rivers. Some part is formed of clay, hard clay or clay mixed with kankar at the top.

4.2 Data Availability:

4.2.1 Measurable Watershed Data:

The test data for the year 1956 for the basin Woodcreek at London, Ky. USA are available with us. The OPSET program is first run with this set of data.

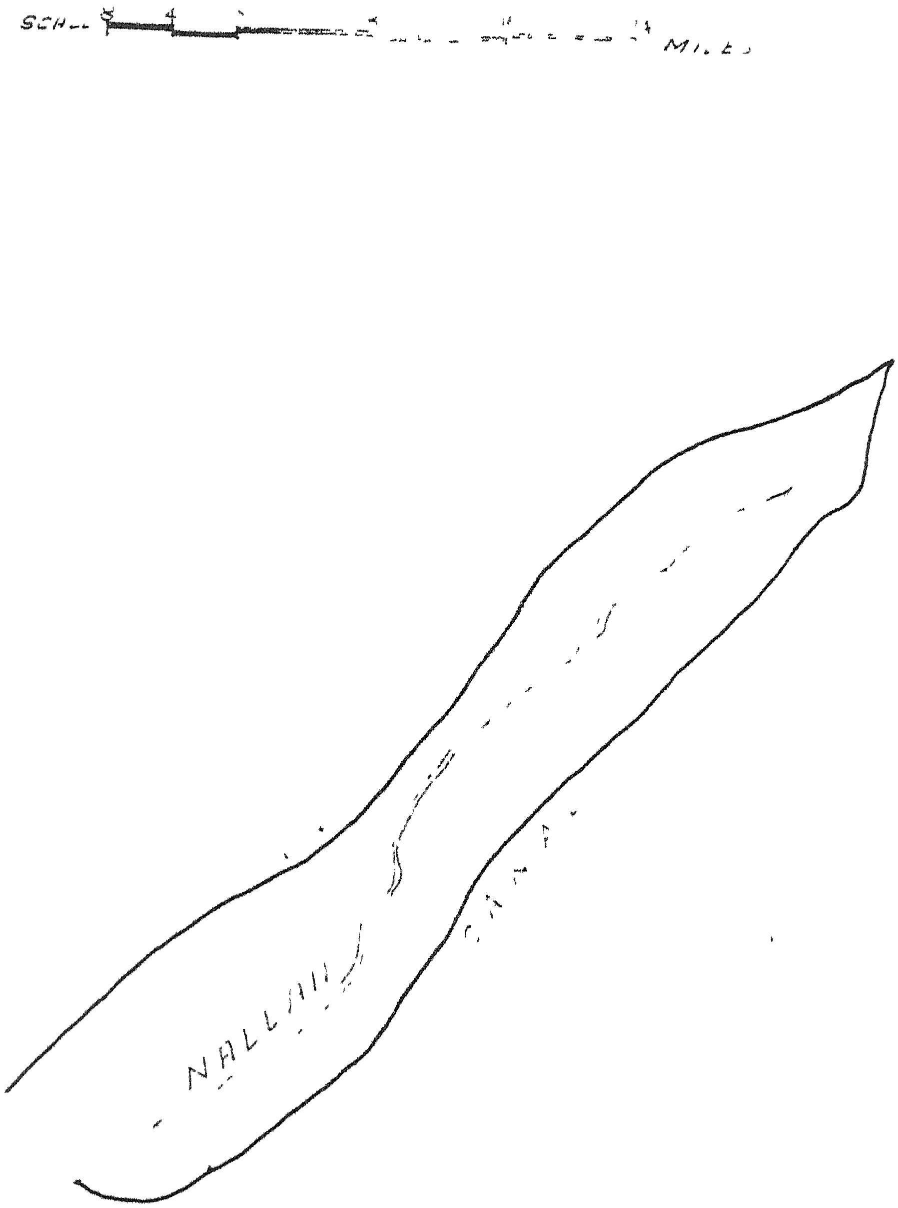


FIG 8 PLAN OF THE BASIN

For the basin in this study the following data were measured as accurately as possible. The description of all these are presented in Chapter 2.

1. AREA:

The maximum value of this is 650 sq.miles. The streamflow data were obtained from different places along the stream in different years. The areas under considerations are also different.

2. FIMP:

The impurvious part of the area is significantly smal This value has been taken as 0.0005.

3. FWTR:

There is no lakes or swamps inside the area. Hence this value is taken as zero.

4. VINTMR:

No forest is observed inside the basin. The value of VINTMR is taken from the Table 1 (Chapter II) as 0.10.

5. GWETF:

As a significant number of phreatophytes or swamps are not known to exist inside the area, this value is taken as zero.

6. SUBWF:

It is assumed that no water leaves the basin through sub-surfaceflow not measured by the stream gauge after entering into the ground water storage from the surface. This value is, therefore, taken as zero.

7. OFSS:

This is obtained from the average of the measurements at randomly selected points on the basin. 4 measurements are taken from which the average **is** calculated as described below:

Measurement No.	Slope (in ft/mile)
1	5
2	2
3	10
4	5

Average slope = 5.5 ft in 1 mile $\simeq$ 0.001 (= 0.1 percent)

8. OFSL:

OFSL can be estimated in different ways. In this study, it is represented as the reciprocal of twice the drainage density (obtained by dividing total lengths of all the streams within the watershed in miles with the total area of the watershed in sq.miles). The calculations is shown below.

Total area of the watershed = 650 sq.miles

Total len th of all the streams inside the watershed = 456.0 miles

Hence, the drainage density $= \dfrac{456.0}{650.0} = 0.70$

$$\text{OFSL} = \frac{1}{2x(\text{drainage density})} = \frac{1}{2 \times 0.70}$$

$$= 0.715 \text{ miles} = 3780 \text{ feet}$$

9. OFMN:

This value is taken from the table given below:

Table 2: Manning's Roughness Coefficient for Overland Flow for Various Surface Types [9]

Watershed Surface	Manning's n
Smooth Asphalt	0.013
Concrete (Trowel finish)	0.013
Rough Asphalt	0.016
Concrete (unfinished)	0.017
Smooth Earth	0.018
Firm Gravel	0.020
Cemented Rubble Masonry	0.025
Pasture (Short grass)	0.030
Pasture (High Grass)	0.035
Cultivated Area (Row Crops)	0.035
Cultivated Area (Field Crops)	0.040
Scattered Brush, Heavy Weeds	0.050
Light Brush and Trees (Winter)	0.050
Light Brush and Trees (Summer)	0.060
Dense Brush (Winter)	0.070
Dense Brush (Summer)	0.100
Heavy Timber	0.100

OFMN is taken for the basin as 0.035.

10. OFMNIS:

This value is also taken from the above table. For the present study it is taken as 0.018.

11. CHCAP:

The size of the channel at the gauging point may not be the size of the channel system as a whole. This can be measured from the hydraulic analysis of the profile and the cross section of the stream channel. Another method is to measure the gauge height of the bankful flow from the topographic map and then to read the CHCAP value directly from the stream gauge rating table. In this study CHCAP is indexed to the outlet of the basin and is taken as more than the measured maximum discharge.

12. DIV:

There is no flow diversion into or out of the stream and hence this value is taken as zero for the watershed in the study.

4.2.2 Meteorological Data:

1. Evaporation Data:

Pan evaporation data are available for one station near the basin. Evaporation data are recorded with mesh covered fixed point gauge, class 'A' pan evaporimeter. These values were in millimeters and are converted to inches by multiplying with 0.03937.

2. Pan Coefficients:

In this study these values are taken from the table given in Ref. 10. Starting from the month of January upto December, these values are 1.00, 1.00, 0.90, 0.75, 0.70, 0.70, 0.75, 0.90, 0.95, 0.90, 1.00 and 1.10.

3. Daily Hourly Precipitation Data:

These are recorded for one rain gauge station near the basin by a self recording rain gauge. These values are obtained again in mm and were converted to inches.

4. Daily Rainfall Data:

Daily rainfall data are also collected from an ordinary rain gauge station inside the basin. This raingauge is called in the program as the secondary rain gauge. The values obtained in mm were converted to inches.

Evaporation, hourly rainfall, daily rainfall and discharge data are collected for a few years. All the data are not available for the same place inside the basin. Two years data have been run but it is found that only in one particular year the rainfall data is in consistence with the discharge data.

5. Stream Flow Data.

This data is collected from the drainage nallah of the basin. Discharge data are not available for the basin for the same place for different years. These are available in different location in different years.

The basin is approximately rectangular in size and so the area covered by each stream gauge station is taken as linearly proportional to the distance of the stream gauge from the farthest end of the basin.

4.3 Simulation Analysis:

4.3.1 Initialization of Parameter Values:

OPSET optimizes 13 parameters altogether. These are, LZC, BMIR, SUZC, ETLF, BUZC, SIAC, BIVF, BFRC, IFRC, CSRX, FSRX, ICTRI, CHCAP.

The following are the initial values of first six parameters inside the program.

Table 3: Initial Values of Parameters (Ref. 8, p. 33).

Parameter	Starting Values Low	Middle	High
LZC	2.00	12.00	30.00
BMIR	0.20	1.20	4.00
SUZC	0.30	1.30	4.00
ETLF	0.05	0.25	0.60
BUZC	0.20	1.50	5.00
SIAC	0.30	0.90	4.00

For the consistent estimate of reasonable parameter values the medium starting values worked best because they give the best chance of being close to the final estimate and less chance to produce out-of-range adjusted values which may cause the program to stop before the optimum point is reached (Ref. 8, p. 34).

The initial values of the other parameters are as follows:

BIVF = 0.0 , FSRX = CSRX = SRX = 0.98

IFRC = 0.1 , BFRC = 0.9

4.3.2 Control Options:

1. CONOPT:

The OPSET program has the control options, expressed by CONOPT (1), CONOPT (2) and CONOPT (3).

CONOPT (1) = 0, if daily evaporation data are used.

= 1, if evaporation is read by 10 day period.

= 2, if annual evaporation is read and the subroutine EVPDAY is used.

CONOPT (2) = 0, if stream routing is to be done with 15 minutes time interval.

= 1, if stream routing is to be done with hourly time interval.

CONOPT (3) = 0, if no change in WSG or SGRT occur during the water year.

= 1, if storage gauge was moved during the water year.

In the test data CONOPT (1), CONOPT (2) and CONOPT (3) were taken as 2, 0 and 1 respectively. For the Indian data in this study these are taken as 1,1, and 0.

. MNRC, NFTR, and NLTR:

These are another set of control options which are given below:

MNRC = Minimum number of rough cycles to be made.

NFTR = Number of first trip to be run for a given year.

NLTR = Number of last trip to be run for a given year.

In all the cases, the values of MNRC, NFTR and NLTR are taken as 12, 1 and 3 respectively.

.4 Output Parameters Using the Test Data:

Test data [4] have been run through the OPSET program. omparative study of these output parameters and that given in he report [8] is given in the following table.

Table 4: Comparison of Obtained Parameter Values with those given in the Ref. 8.

Sl. No.	Parameter	Value given in the report	Value obtained from the program
1	LZC	11.14	11.76
2	BMIR	4.23	4.99
3	SUZC	0.65	0.65
4	ETLF	0.15	0.15
5	BUZC	1.04	1.09
6	SIZC	0.45	0.45
7	BIVF	0.00	0.00
8	CSRX	0.935	0.939
9	FSRX	0.935	0.939
0	NCTRI	3.	3
1	IFRC	0.10	0.10
2	BFRC	0.895	0.894
3	CHCAP	100.0	100.0

In addition, the LZS value found in the report to be 58 and that obtained from the program is 8.83.

The synthesized and the recorded monthly flows and peak drographs are compared and shown in Table 5 and Table 6 spectively on the other pages.

Table 5: Comparison of Recorded and Synthesized Monthly flows for the Test Data.

Month	Recorded flow	Synthesized flow
October 1955	13.5	6.6
November 1955	11.8	8.2
December 1955	21.3	22.3
January 1956	63.9	107.4
February 1956	779.8	719.9
March 1956	469.4	451.4
April 1956	465.1	456.9
May 1956	160.5	78.6
June 1956	28.3	30.0
July 1956	202.3	263.2
August 1956	51.9	49.5
September 1956	26.5	117.5
Yearly Total	2294.3 sfd	2311.5 sfd

Table 6: Comparison of Recorded and Synthesized Hydrograph Peaks for the Test Data.

Date	Recorded		Synthesized	
	Peakflow (cfs)	Time	Peakflow (cfs)	Time
Feb. 17, 1956	506.0	11 PM	458.4	6.15 AM
Mar. 14, 1956	264.0	6 AM	213.1	6.00 AM
Apr. 6, 1956	133.0	10 AM	109.3	9.15 AM
Apr. 15, 1956	227.0	9 AM	355.7	8.30 AM

From the results shown in the preceding tables, it is evident that the model has been implemented with reliable accuracy. Here the lowest value of SSQM = 3.69

Obtaining fairly accurate results with the test data the model was then applied to an Indian basin. The following are the results obtained for the basin.

Table 7: Recorded and Synthesized Stream Flow For the Year 1971-72.

Months	Recorded	Synthesized
June	20.0	182.4
July	1306.0	2849.6
August	12460.0	9817.2
September	983.0	585.9
October	0.0	15.6
November	0.0	0.5
December	0.0	0.0
January	0.0	0.1
February	0.0	2.2
March	0.0	0.2
April	0.0	0.3
May	0.0	0.0
Yearly Total	14769.0 sfd	13454.0 sfd

Table 8: Comparison of Recorded and Synthesized Hydrograph Peaks for the Year 1971-72.

Date	Recorded		Synthesized	
	Peakflow (cfs)	Time	Peakflow (cfs)	Time
July 30	110.0	12 AM	121.0	0.15 AM
August 5	1950.0	12 AM	1898.8	1.00 AM
August 28	480.0	12 AM	122.8	0.15 AM

Lowest SSQM = 2.674

Table 9: Recorded and Synthesized Streamflow for the year 1969-70.

Months	Recorded Flow	Synthesized Flow
June 1969	0.0	6.0
July 1969	3416.0	634.5
August 1969	5850.0	11171.9
September 1969	2191.0	3464.9
October 1969	0.0	337.4
November 1969	0.0	41.0
December 1969	0.0	11.8
January 1970	0.0	8.8
February 1970	0.0	19.7
March 1970	0.0	12.0
April 1970	0.0	1.5
May 1970	0.0	1.4
Yearly Total	11457.0 sfd	15710.9 sfd

Table 10: Recorded and Synthesized Hydrograph Peaks for the Year 1969-70

Date	Recorded		Synthesized	
	Peak flow (cfs)	Time	Peak flow (cfs)	Time
29th July '69	425.0	12 AM	--	--
16th Aug. '69	340.0	12 AM	617.7	9.15 AM
13th Se t.'69	140.0	12 AM	123.2	0.15 AM

Lowest SSQM = 86.4999

Table 11: Optimum Parameter Values Obtained for an Indian Basin.

Parameter	Year 1969	Year 1971
LZC	12.0	2.3382
BMIR	--	11.6108
SUZC	1.3	3.0
ETLF	0.092	0.1793
BUZC	1.5	0.2761
SIAC	4.0	3.6
BIVF	0.0	0.0
BFRC	0.9267	0.8884
IFRC	0.10	0.10
CSRX	0.9950	0.90
FSRX	0.9950	0.90
NCTRI	47	25
CHCAP	2500	2000

Table 12: Recorded Flows for Test Data at Wood Creek, London, Ky, USA, 1955-56.

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1	0.4	0.3	0.3	0.5	5.7	8.6	4.0	5.6	3.2	8.7	4.7	3.5
2	0.4	0.3	0.6	0.5	20.0	8.6	6.4	35.0	1.6	1.2	4.3	1.2
3	0.3	0.3	1.6	0.5	36.0	11.0	7.1	22.0	1.5	0.8	3.7	0.7
4	0.3	0.3	3.0	0.4	47.0	9.2	19.0	12.0	1.3	0.7	3.7	0.7
5	0.3	0.3	1.5	0.4	22.0	8.2	9.8	9.2	1.2	4.7	2.9	0.6
6	0.3	0.3	1.0	0.4	35.0	7.6	50.0	7.9	1.1	1.8	2.7	6.1
7	1.8	0.3	0.9	0.4	20.0	26.0	30.0	7.0	0.9	1.1	2.7	2.1
8	0.6	0.3	0.7	0.4	12.0	34.0	17.0	6.2	0.9	0.9	2.0	1.2
9	0.4	0.2	0.7	0.3	9.5	19.0	12.0	4.8	0.9	1.0	1.6	0.8
10	0.4	0.3	0.6	0.4	7.9	13.0	9.8	4.2	0.8	0.9	1.5	0.7
11	0.3	0.3	0.6	0.4	13.0	10.0	8.2	3.8	0.7	0.6	1.6	0.6
12	0.3	0.2	0.5	0.4	10.0	11.0	7.0	3.4	0.7	0.5	1.3	0.6
13	1.4	0.2	0.5	0.3	9.2	15.0	6.2	3.0	0.7	11.0	1.3	0.5
14	0.6	0.2	0.5	0.3	13.0	103.0	7.2	2.8	0.6	14.0	1.4	0.4
15	0.5	0.3	0.5	0.3	17.0	35.0	94.0	2.8	0.6	3.9	1.2	0.5
16	0.4	0.3	0.4	0.4	14.0	27.0	59.0	2.6	0.5	8.6	1.1	0.5
17	0.4	0.3	0.4	0.3	103.0	18.0	29.0	2.2	0.5	6.6	0.9	0.4
18	0.4	0.3	0.6	0.3	143.0	16.0	17.0	2.1	1.4	4.7	0.9	0.4
19	0.4	1.1	0.6	2.0	44.0	12.0	12.0	2.0	1.8	3.5	0.9	0.4
20	0.3	0.4	0.5	0.7	25.0	9.8	9.2	1.8	0.9	5.8	2.0	0.4
21	0.3	0.3	0.5	0.6	16.0	8.9	7.6	1.5	1.1	6.5	1.5	0.4
22	0.3	0.3	0.5	0.6	12.0	7.6	7.0	1.4	0.9	2.7	1.2	0.4
23	0.3	1.9	0.5	0.6	10.0	6.8	6.5	1.4	0.6	15.0	1.0	0.6
24	0.3	0.6	0.5	0.5	35.0	7.6	5.6	1.3	0.5	22.0	0.9	0.5
25	0.3	0.5	0.5	0.5	39.0	6.2	4.8	1.2	1.3	18.0	0.9	0.4
26	0.3	0.4	0.5	0.5	24.0	5.6	4.4	1.2	0.5	14.0	0.8	0.4
27	0.3	0.4	0.4	0.5	16.0	5.1	4.0	1.3	0.4	10.0	0.8	0.4
28	0.3	0.3	0.4	0.6	12.0	5.9	3.6	3.6	0.4	8.6	0.8	0.4
29	0.3	0.3	0.4	11.0	9.5	5.1	3.4	3.6	0.4	11.0	0.7	0.4
30	0.3	0.3	0.6	33.0	-	4.4	4.3	2.0	0.4	7.8	0.7	0.4
31	0.3	-	0.5	5.9	-	4.2	-	1.6	-	5.7	0.7	-

Table 13: Synthesized Flow for Test Data at Wood Creek, London, Ky,USA, 1955-56.

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept.
1	0.3	0.0	0.4	0.2	7.6	7.4	3.3	2.6	3.7	17.2	5.1	3.5
2	0.3	0.0	0.7	0.1	11.2	7.5	39.7	7.2	2.9	2.2	4.6	2.1
3	0.2	0.0	2.1	0.1	31.7	28.2	14.8	5.2	2.5	1.8	4.0	1.5
4	0.2	0.0	2.1	0.1	63.9	8.2	22.1	4.1	2.2	1.6	3.6	1.3
5	0.2	0.0	1.6	0.1	14.1	6.5	5.8	3.7	2.0	1.9	3.2	1.3
6	0.2	0.0	1.4	0.1	43.6	5.9	108.9	3.3	1.8	1.6	2.8	63.7
7	0.8	0.0	1.3	0.1	11.0	79.6	10.0	2.9	1.6	1.5	2.5	17.3
8	0.3	0.0	1.2	0.1	9.8	10.6	7.2	2.6	1.4	1.3	2.2	3.2
9	0.2	0.0	1.2	0.1	8.7	6.6	6.4	2.3	1.2	1.3	2.0	2.9
10	0.2	0.1	1.1	0.1	7.8	5.9	5.7	2.0	1.1	1.1	1.8	2.5
11	0.2	0.0	0.9	0.1	26.5	9.7	5.1	1.8	0.9	1.0	1.5	2.3
12	0.2	0.0	0.8	0.1	8.7	24.5	4.6	1.6	0.8	1.1	1.4	2.0
13	0.8	0.0	0.8	0.1	8.0	24.6	4.1	1.4	0.7	4.8	1.3	1.8
14	0.4	0.0	0.7	0.1	23.0	72.8	6.9	1.3	0.8	5.5	1.1	1.6
15	0.3	0.2	0.6	0.1	10.8	10.8	115.3	1.3	0.6	6.0	0.9	1.5
16	0.3	0.1	0.5	0.1	11.3	25.5	22.2	1.1	0.6	7.4	0.8	1.5
17	0.3	0.5	0.5	0.1	158.8	10.3	9.2	0.9	0.4	20.0	0.7	1.1
18	0.2	0.1	0.7	0.1	72.4	14.6	8.2	0.8	0.5	6.4	0.6	1.0
19	0.2	0.9	0.5	1.5	15.5	9.2	7.3	0.7	0.3	4.8	0.7	0.9
20	0.2	0.5	0.5	0.7	13.6	8.2	6.5	0.6	0.4	8.5	0.8	0.8
21	0.1	0.5	0.4	0.6	12.2	7.3	5.8	0.5	1.0	5.4	0.5	0.7
22	0.1	0.4	0.4	0.6	10.9	6.5	5.7	0.5	0.4	4.6	0.4	0.7
23	0.1	1.3	0.3	0.6	9.9	5.9	5.7	0.4	0.4	15.6	0.4	0.5
24	0.1	0.7	0.3	0.5	66.9	13.9	5.1	0.5	0.4	77.4	0.3	0.5
25	0.1	0.7	0.3	0.6	23.9	5.7	4.5	0.4	0.4	12.7	0.3	0.4
26	0.1	0.6	0.2	0.5	10.8	5.1	4.0	0.3	0.3	15.6	0.2	0.4
27	0.1	0.5	0.2	0.5	9.7	4.5	3.6	0.3	0.2	8.4	0.3	0.3
28	0.1	0.5	0.2	0.7	8.8	13.3	3.2	1.4	0.2	7.3	3.4	0.4
29	0.0	0.4	0.2	75.4	7.9	5.3	3.1	19.9	0.2	7.4	0.8	0.2
30	0.0	0.4	0.2	18.6	-	4.2	2.7	4.6	0.2	6.4	0.7	0.2
31	0.0	-	0.2	9.4	-	3.7	-	2.5	-	5.7	0.6	-

Table 15: Synthesized Daily Flows (Indian Basin, 1971-72) (cfs)

DAY	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.
1	0.0	70.8	101.0	70.2	2.3	0.1
2	0.0	90.6	841.9	62.3	2.0	0.1
3	0.0	185.8	1277.3	59.5	1.8	0.1
4	0.0	194.6	1115.2	55.9	1.6	0.1
5	0.0	208.3	724.9	49.6	1.4	0.0
6	0.0	207.0	591.2	44.1	1.3	0.0
7	0.0	192.5	517.5	39.2	1.1	0.0
8	0.0	175.5	458.5	34.8	1.0	0.0
9	0.0	158.1	407.0	30.9	0.9	0.0
10	0.0	141.4	361.5	27.5	0.8	0.0
11	0.0	125.9	321.0	24.4	0.7	0.0
12	0.0	111.9	285.1	21.7	0.6	0.0
13	0.0	99.4	253.4	19.2	0.6	0.0
14	0.0	88.3	224.9	17.1	0.6	0.0
15	0.0	78.4	199.7	15.2	0.5	0.0
16	0.0	69.6	177.4	13.5	0.4	0.0
17	0.0	61.8	190.9	12.0	0.4	0.0
18	0.0	71.6	174.1	10.6	0.4	0.0
19	0.0	79.5	154.6	9.4	0.3	0.0
20	0.0	70.6	137.3	8.4	0.3	0.0
21	0.0	62.6	121.9	7.4	0.2	0.0
22	0.0	55.6	108.3	6.6	0.2	0.0
23	0.0	49.4	96.2	5.9	0.2	0.0
24	0.1	70.7	85.4	5.2	0.2	0.0
25	2.3	69.0	75.8	4.6	0.2	0.0
26	20.8	68.8	79.9	4.1	0.1	0.0
27	30.7	65.9	113.9	3.7	0.1	0.0
28	29.2	58.5	112.8	3.2	0.1	0.0
29	28.4	94.8	100.2	2.9	0.1	0.0
30	27.8	128.1	89.0	2.6	0.1	0.0
31	-	113.8	79.0	-	0.1	-

Flows in the other months are all zero.

Table 16: Recorded Daily Flows (Indian Basin, 1969-70). (cfs)

DAY	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.
1	0.0	0.0	305.0	102.0	0.0	0.0
2	0.0	0.0	305.0	102.0	0.0	0.0
3	0.0	0.0	283.0	100.0	0.0	0.0
4	0.0	0.0	262.0	100.0	0.0	0.0
5	0.0	0.0	242.0	100.0	0.0	0.0
6	0.0	0.0	242.0	90.0	0.0	0.0
7	0.0	0.0	18[illegible].0	85.0	0.0	0.0
8	0.0	0.0	150.0	65.0	0.0	0.0
9	0.0	45.0	120.0	65.0	0.0	0.0
10	0.0	40.0	118.0	110.0	0.0	0.0
11	0.0	45.0	115.0	115.0	0.0	0.0
12	0.0	50.0	115.0	120.0	0.0	0.0
13	0.0	55.0	118.0	134.0	0.0	0.0
14	0.0	58.0	134.0	125.0	0.0	0.0
15	0.0	60.0	140.0	110.0	0.0	0.0
16	0.0	62.0	327.0	100.0	0.0	0.0
17	0.0	66.0	305.0	100.0	0.0	0.0
18	0.0	66.0	305.0	90.0	0.0	0.0
19	0.0	70.0	262.0	92.0	0.0	0.0
20	0.0	66.0	184.0	86.0	0.0	0.0
21	0.0	60.0	262.0	60.0	0.0	0.0
22	0.0	50.0	184.0	45.0	0.0	0.0
23	0.0	66.0	150.0	40.0	0.0	0.0
24	0.0	66.0	167.0	30.0	0.0	0.0
25	0.0	150.0	160.0	25.0	0.0	0.0
26	0.0	327.0	131.0	0.0	0.0	0.0
27	0.0	350.0	134.0	0.0	0.0	0.0
28	0.0	424.0	120.0	0.0	0.0	0.0
29	0.0	450.0	115.0	0.0	0.0	0.0
30	0.0	400.0	110.0	0.0	0.0	0.0
31	-	380.0	102.0	-	0.0	-

Flows in the other months are all zero.

Table 17: Synthesized Daily Flows (Indian Basin, 1969-70) (cfs)

DAY	JUNE	JULY	AUGUST	SEPT.	OCT.	NOV.
1	0.0	1.2	39.9	270.0	30.3	0.0
2	0.0	1.2	77.6	250.2	28.1	0.0
3	0.0	1.1	96.0	231.8	26.0	0.0
4	0.0	1.0	215.9	214.8	24.1	0.2
5	0.0	0.9	258.4	199.0	22.4	0.0
6	0.0	0.9	241.0	184.4	20.7	0.0
7	0.0	0.8	223.3	171.0	19.2	0.0
8	0.0	2.7	218.2	158.7	17.8	0.0
9	0.0	3.2	295.4	147.0	16.5	0.0
10	0.0	3.0	330.5	136.2	15.3	0.0
11	0.0	3.1	307.9	132.3	14.1	0.0
12	0.0	3.3	286.0	127.8	13.1	0.0
13	0.0	5.4	265.2	118.4	12.1	0.0
14	0.0	6.7	246.0	109.7	11.3	0.0
15	0.0	6.6	262.0	101.7	10.4	0.0
16	0.0	7.4	577.6	94.0	9.7	0.0
17	0.0	10.2	594.7	87.3	8.9	0.0
18	0.0	9.2	613.8	81.5	8.3	0.0
19	0.0	8.8	627.2	75.7	7.7	0.0
20	0.0	8.2	582.7	70.2	7.1	0.0
21	0.0	20.0	539.9	65.0	6.6	0.0
22	0.0	26.9	548.5	60.3	6.1	0.0
23	0.0	40.4	534.4	55.8	5.6	0.0
24	0.0	72.9	495.5	51.7	5.3	0.0
25	0.0	67.7	460.6	47.9	4.9	0.0
26	0.1	62.7	426.7	44.4	4.5	0.0
27	0.2	58.1	395.4	41.0	4.2	0.0
28	1.6	49.9	366.4	38.1	3.9	0.0
29	1.5	53.8	339.5	35.3	3.6	0.0
30	1.3	46.4	314.5	32.7	0.0	0.0
31	-	43.0	291.4	-	0.0	-

Flows in the other months are very negligible.

CHAPTER V

DISCUSSIONS AND CONCLUSIONS

5.1 Discussion of the Results:

5.1.1 SSQM:

SSQM is the sum of squares of deviations for 11 months and it is used to indicate which set of volume parameter values gives the best synthesis of flow volumes. The first month of the water year is excluded from this least square term because the flows in the first month are too dependent on unknown initial conditions. The final value of SSQM gives a reliable indication as to how best the parameters are synthesized with respect to the input data.

5.1.2 Test Data:

After going through the results from the test data, it is observed that the optimized 13 output parameters are closely comparable with the reported values [8]. The recorded daily stream-flow and the synthetic flow, as shown in the Tables 12,13 are also comparable. In addition, from Table 6, it is clear that peak hydrograph values also matched well. Hence the OPSET program is well implemented, in the computer system available with us. Monthly flows are compared in Fig. 9.

5.1.3 Indian Data:

After analysing the output for 2 years for Indian data the following observations can be made.

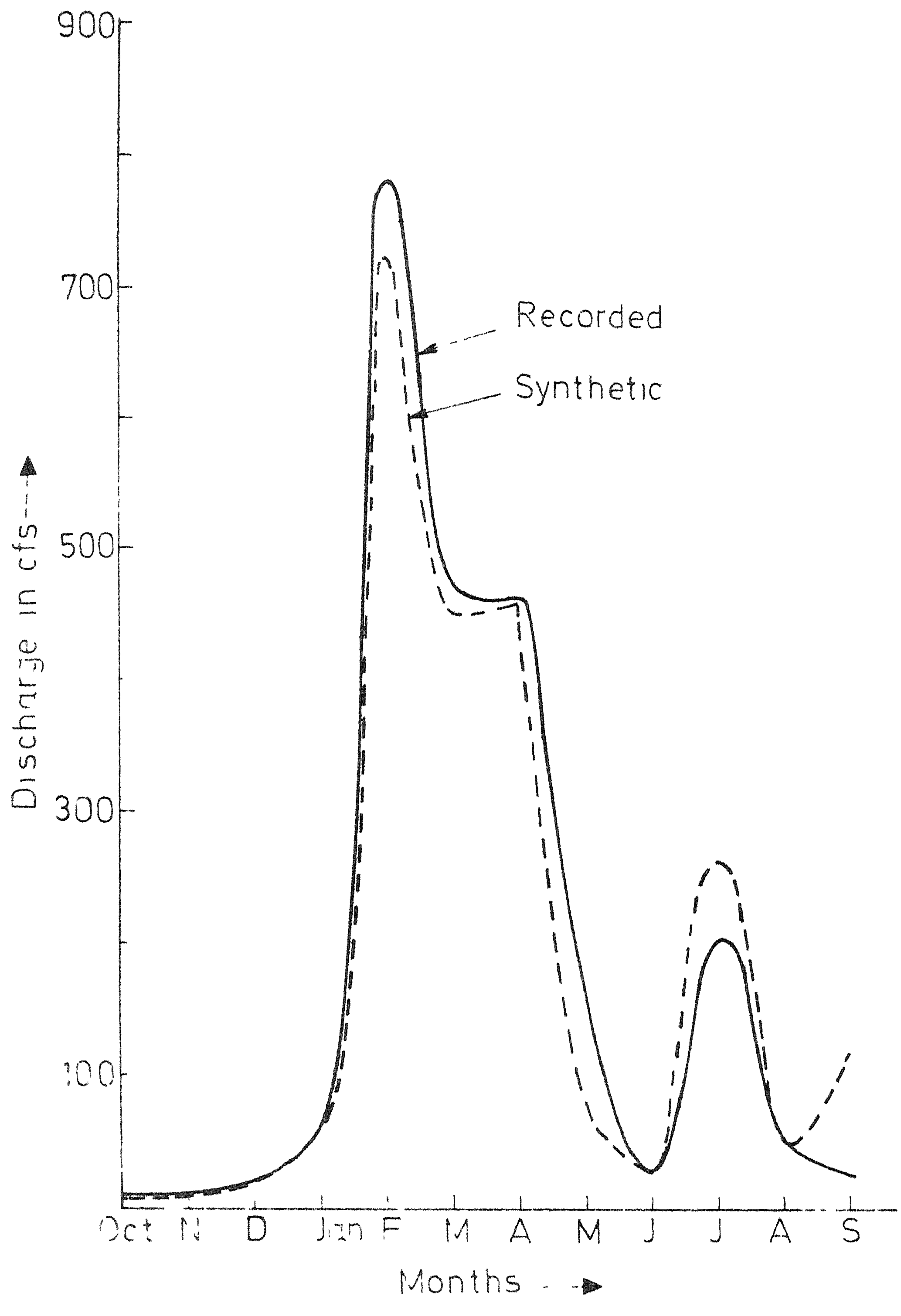


FIG.9 TEST DATA-WOOD CREEK, USA, WATER YEAR 1956
(MONTHLY FLOW)

Year 1969-70:

From the table 16,17,it is observed that the daily recorded stream flow did not match with the daily synthesized stream flow. Similarly the monthly flows and the yearly totals of recorded and synthesized stream flows have wide gap. Peak hydrograph values between the observed and the synthetic cannot be compared. Hence the parameter values obtained on the basis of this year data are not correct. SSQM value in this year is high. The daily recorded and synthesized flows are shown in Fig. 11.

Year 1971-72:

From the Figure 10 and the Tables 14 and 15of the daily stream flow hydrograph and the monthly totals respectively for the observed and the synthesized values, it is seen that these two matched well. Again the recorded hydrograph peak values can be compared with the synthesized hydrograph peak values. The SSQM value is very low in this year. Hence the parameter values for the year 1971-72 are taken as the optimum parameters for the basin. These values are:

LZC = 2.338 ,	BMIR = 11.610 ,	SUZC = 3.00,
ETLF = 0.1793 ,	BUZC = 0.2761 ,	SIAC = 3.60,
BIVF = 0.0 ,	BFRC = 0.8884 ,	IFRC = 0.10,
CSRX = 0.90 ,	FSRX = 0.90 ,	NCTRI = 25 and
CHCAP = 2000.		

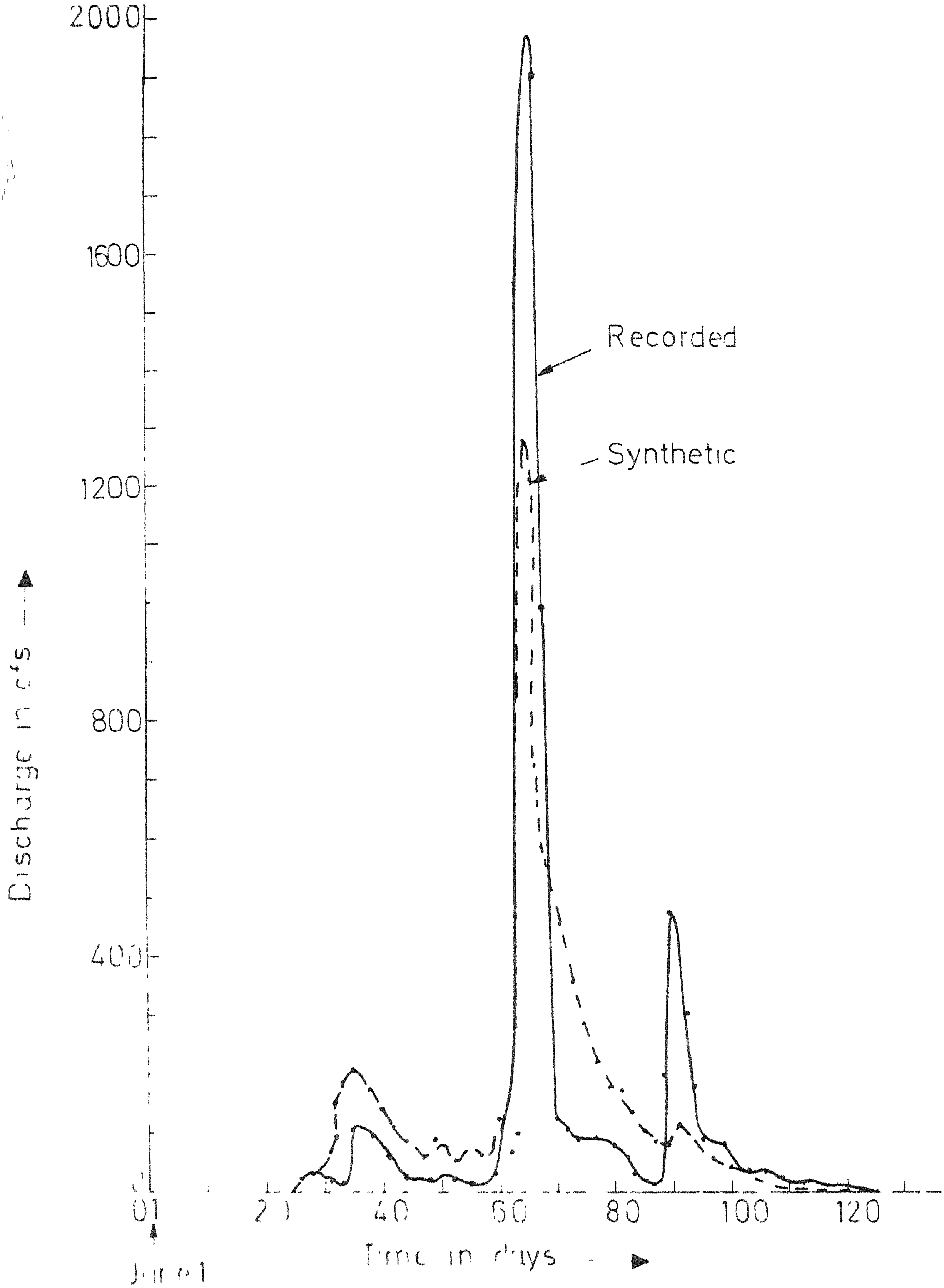


FIG 10 RECORDED AND SYNTHESIZED DAILY FLOWS OF INDIAN BASIN WATER YEAR 1971-72

It is clear that the results obtained for the Indian basin are not really accurate. Also, the results from the different years are not equal to each other. This is basically due to the following factors.

(i) All the rain gauge stations whose recorded hourly and daily rainfalls, used in the present work, are not situated within the basin. So the rainfall pattern fed to the program is different from the actual pattern.

(ii) Streamflow records are not reliable. Some values are missing and some are not observed.

(iii) Topographic sheet for the area is not available.

(iv) Watershed area is large.

(v) Unlike the test data for rainfall, the rainfall in the basin under study occur mainly for 3 months in a year.

(vi) The peak flow discharge data are not available.

(vii) The streamflow gauging points are different in different years.

However, the parameter values obtained from the data for the year 1971 are the better of the two. They can be taken as very good approximation for the parameters of the watershed. This can be inferred from the following reasons:

(i) In the year 1971 the rainfall and streamflow patterns are comparable.

(ii) SSQM value is very low in this year.

(iii) With days passing, the data availability also is more. The data which are not available for the preceding years are available for the year 1971. Hence, the results also can be considered better.

5.2 Conclusions and Scope of Further Studies.

Through the OPSET program very good prediction of annual streamflow and fairly good prediction of monthly streamflow are obtained. Flood hydrographs are simulated less accurately.

Natural phenomena being simulated are frequently too complex to permit an intricate analysis and to simplify these further research is necessary.

Measurable watershed parameters should be measured very accurately and the proper authorities should be well informed in advance to keep the necessary data for further studies. Peak flows are very much needed for estimating the channel routing parameters.

OPSET program should be applied in different watersheds varying in sizes, locations and climatological conditions.

Effect in the changes in the watershed such as urbanization and agricultural land use should also be studied through this program.

For larger watersheds, it is better to subdivide the total area into parts, each with its own set- of parameters,

and combine these results by stream routing.

Further detailed studies should be made to find out the ground water re-charge through this model.

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APPENDIX

COMPARISON OF ANNUAL RUNOFF CALCULATEL BY OPSET METHOD WITH THAT BY AN APPROXIMATE METHOD

TEST DATA: Year 1956, Wood Creek, Ky, USA.

Approximate Method:

Runoff = Rainfall - Evapotranspiration

In this year of test data

Rainfall = 53.86 inches.

Evapotranspiration (Potential) = 35.785 inches.

Annual Runoff = (53.86 - 35.785) = 18.075 inches.

Totalarea of the watershed = 3.89 **square miles**

$$\text{Annual Run off} = \frac{3.89 \times (5280)^2}{12 \times 86400} \times 18.075 = 1920 \text{ sfd}$$

Net evapotranspiration calculated by OPSET program i 29.094 inches.

Hence Annual Runoff = (53.86 - 29.094) = 24.766 inches.

$$= \frac{3.89 \times (5280)^2}{12 \times 86400} \times 24.766 = 2582 \text{ sfd}$$

Annual Runoff calculated by OPSET = 2311.5 sfd.

It seems that the net evapotranspiration value gives the better result in Approximate method.

For Indian data the total annual evapotranspiration values always exceeded the net precipitation in the year and hence the above method could not be used. Khosla's method could not be applied due to non-availability of the value of the constant for the catchment under consideration.

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          ..........................................................
                  LISTING  OF  THE  COMPUTER  PROGRAMME
          ..........................................................




          ..........................................................
C    COMPUTER PROGRAM ON HYDROLOGIC SIMULATION
C   OPSET
C   A SELF-CALIBRATING VERSION OF THE STANFORD WATERSHEDMODEL
C BASIC LOGIC OF INNER LOOP BASED ON STANFORD WATERSHED MODELS III AND I
C    VERSIONOF NOVEMBER 12,1970
C   ****************************************************************
C   *
C   *
C     IMPLEMENTED  FOR  THE  SYSTEMS  IBM 7044  AND  IBM  370/155
C   *
C   *
C   ****************************************************************
C       IN  THIS STUDY  WATER YEAR  STARTS  FROM  JUNE 1
C     DAY = 274  IN  THE  PROGRAMME  IS  TAKEN  FOR  JUNE 1
C   MONTHS IN THE TABULATED RECORDED AND SYNTHESIZED FLOWS ARE CHANGED
C   IN THE NEW FORMAT ALSO DATES SHOULD BE READ AS FOLLOWS
C******************** JUNE 1 AS JUNE 1    ******************************
C******************** JULY 1 AS JULY 2    ******************************
C******************** AUG 1 AS AUG 2      ******************************
C******************** SEPT1 AS SEPT1      ******************************
C******************** OCT 1 AS OCT 2      ******************************
C*********************  NOV 1 AS OCT 30   ******************************
C********************  DEC 1 AS NOV 30    ******************************
C******************** JAN 1 AS DEC 30     ******************************
C******************** FEB 1 AS JAN 30     ******************************
C******************** MAR 1 AS MAR 1      ******************************
C*********************   APR 1 AS APR 1   ******************************
C*********************   MAY 1 AS MAY 2   ******************************
          ..........................................................
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```
      DIMENSION BTRI(99), CONOPT(5),CTRI(99), DRGPM(366),DRHP(366,24),
     1  DRSGP(366),DPET(366), DRSF(366), DSSF(366), EMGWS(12),
     2  EMIFS(12), EMLZS(12),EMSIAM(12),EMUZC(12),EMUZS(12),
     3  EPCM(12), HBF(5), IDYB(5), IDYE(5), IHRB(5),IHRE(5),  KPSH(5),
     4 LSHA(5),MEDCY(12),MEDWY(12),RHPD(5),RHPF(5),RHPH(5)
      DIMENSION RSBBF(20),RSBD(20),RSBIF(20),SBFRS(3,20)
     6 ,THSF(24), TITLE(20), TMBF(12),TMIF(12), TMNET(12), TMOF(12),
     7  TMPET(12), TMPREC(12), TMRTF(12), TMSE(12), TMSTF(12),
     8TMSTFI(12),UHFA(99),XMPFT(12),DUM(368),SIFRS(3,20),SSR(5,170)
      LOGICAL LBMIR, LBUZC, LETLF,LLZC, LNPR, LRC, LSHA, LSHP
      INTEGER CN, CCNOPT, DATE, DAY, DPY, EHSGD, HOUR,HRF,HRL,PDAY,
     1  PRD,RHPD,RHPH, RSBD,  SGMD,SGRT,SGRT2,TRIP,YEAR,YR1,
     2  YR2
      REAL IFPRC,IFRC,  IFRL,IFS,LZC ,LZRX,LZS,LZSR, MNRD, NHPT
      DATA MEDCY/  0,        31,59,90,120,151,181,212,243,273,304,334/
      DATA  MEDWY/304,334,365,31,59,90,120,151,181,212,243,273        /
C SPECIFY NUMBER OF STATION-YEARS INCLUDED IN COMPUTER RUN
      NSYC = 0
      READ 500,NSYT
  500 FORMAT(5I5)
  100 NSYC = NSYC + 1
C  READ TITLE TO COMPUTER RUN
      READ (5,1) TITLE
    1 FORMAT(20A4)
C   READ CONTROL OPTIONS
      READ 101  , (CCNOPT(I),I=1,3)
  101 FORMAT(3I2)
      READ 101,MNRC,NFTR,NLTR
C  READ BASIC TIME-AREA HISTOGRAM
      DO 102 KIA = 1,99
      BTRI(KIA) =0.0
  102 UHFA(KIA) = 0.0
      READ 500,NBTRI
      READ 103,(BTRI(J),J=1,NBTRI)
  103 FORMAT(8F10.5)
C  SET INITIAL CONDITIONS
      IFT = 1
      LRC=.TRUE.
      LLZC =.FALSE.
      LBUZC =.FALSE.
      LBMIR =.FALSE.
      LETLF = .FALSE.
      LNPR = .FALSE.
      IF(CONOPT(2) .EQ . 0 .AND. NBTRI.LE. 6) LNPR= .TRUE.
      KRC= 1
      KBRC = 0
      KFFC = 0
      SSSQM= 950.0
      SGRT = 0
C  READ FIXED PARAMETERS
  104 READ 103,RMPF,CHCAP
      READ 103,RGPME,AREA,FIMP,FWTR
      READ 103,VINTMR,SUBWF,GWETF,OFSS,OFMN,OFMNIS,OFSL,DIV
```

```
C   CALCULATE CONSTANTS SET BY FIXED PARAMETERS
      FPER = 1.0 -FIMP-FWTR
      IF(FPER .GT. 0.01) GOTO 105
      TPLR = 100.0
      FPER = 0.01
      GO TO 106
  105 TPLR = (1.0-FWTR)/FPER
  106 VWIN = 26.8888*AREA
      WCFS = 24.0*VWIN
      RHFMC = 0.025/WCFS
      SSRT = SQRT(OFSS)
      OFRF = 1020.0*SSRT/(OFMN  *OFSL)
      OFRFIS=1020.0*SSRT/(OFMNIS*OFSL)
      EQDF= 0.00982*((OFMN*OFSL/SSRT)**0.6)
      EQDFIS = 0.00982*((OFMNIS*OFSL/SSRT)**0.6)
      RGPM =RGPMB
C   READ WATER YEAR
      READ 101,YR1,YR2
      DPY = 365
      IF(MOD(YR2,4) .EQ. 0) DPY = 366
C   READ EVAPORATION DATA
      IF(CONOPT( 1) .NE. 1) GO TO 111
      READ 103,(DPET(KRD),KRD=274,360,10)
      DO 990 KRD=274,360,10
  990 DPET(KRD) = 0.03937*DPET(KRD)
      READ 103,(DPET(KRD),KRD=1,273,10)
      PRINT 103, (DPET(KRD), KRD= 1,273,10)
      DO 991  KRD = 1,273,10
  991 DPET(KRD) = 0.03937*DPET(KRD)
      DO 110 IDAY2=1,9
      DO 109 IDAY1= 274,360,10
      DAY= IDAY1 +IDAY2
  109 DPET(DAY)= DPET(IDAY1)
      DO 110 IDAY1=1,273,10
      DAY=IDAY1+ IDAY2
      IF(DAY.GT. 273) GO TO 110
      DPET(DAY) =DPET(IDAY1)
  110 CONTINUE
      DPET(366)=DPET(59)
      DPET(365) = DPET(363)
      DPET(364)= DPET(363)
      GO TO 113
  111 IF(CONOPT(  1) .EQ. 2) GO TO 116
      DAY =274
  112 READ 103,DPET(DAY)
      IF(DAY .EQ. 273) GO TO 113
      CALL DAYNXT(DAY, DPY)
      GO TO 112
  113 READ 103,(EPCM(MONTH),MONTH=1,12)
      PRINT 103, (EPCM(MONTH) , MONTH=1,12)
      EPAET=0.0
      DO 115 DAY =1,DPY
  115 EPAET =EPAET +DPET(DAY)
      IF(EPCM(6) .NE. 1.0) EPAET =0.7*EPAET
```

```
      GO TO 117                                                         SHM01620
      PRINT 103, EPAET,MNRD                                             SHM01630
  116 READ 103,EPAET,MNRD                                               SHM01640
      EMAET =EPAET*(365.0 + MNRD)/404.0                                 SHM01650
      CALL EVPDAY(DPET,EMAET)                                           SHM01660
C   READ DAILY FLOW DATA                                                SHM01670
  117 DRSF(366)= 0.0                                                    SHM01680
  118 DAY =274                                                          SHM01690
      READ 1000, (DUM(J),J=1,DPY)                                       SHM01700
      PRINT 1000,(DUM(J), J=1,DPY)                                      SHM01710
      ISEQ=1                                                            SHM01720
  119 DRSF(DAY)=DUM(ISEQ)                                               SHM01730
      ISEQ=ISEQ+1                                                       SHM01740
 1000 FORMAT(13F6.1)                                                    SHM01750
      CALL DAYNXT(DAY,DPY)                                              SHM01760
      IF(DAY .NE. (396-DPY))  GO TO 119                                 SHM01770
      IF(DIV .EQ. 0.0) GO TO 122                                        SHM01780
      DO 121 DAY = 1,DPY                                                SHM01790
      IF(DRSF(DAY) .GT. DIV) GO TO 120                                  SHM01800
      DRSF(DAY)= 0.0                                                    SHM01810
      GO TO 121                                                         SHM01820
  120 DRSF(DAY)= DRSF(DAY) -DIV                                         SHM01830
  121 CONTINUE                                                          SHM01840
  122 WRITE(6,2) (TITLE(KTA), KTA =1,20)                                SHM01850
    2 FORMAT(1H1,25X,20A4)                                              SHM01860
C   WRITE DAILY FLOWS                                                   SHM01870
      CALL DAYSUM(DRSF,MEDCY,DPY,RATFV,TMRTF)                           SHM01880
      WRITE(6,3)                                                        SHM01890
   3  FORMAT(1H0,42X,' RECORDED    FLOWS ')                             SHM01900
      CALL DAYOUT(DRSF,MEDWY,DPY)                                       SHM01910
      WRITE(6,4) (TMRTF(KWD), KWD =1,12),RATFV                          SHM01920
   4  FORMAT(6X,'TOTAL',2X,12F8.1,2X,F10.1,2X,3HSFD)                    SHM01930
C   READ STORM HYDROGRAPH DATA                                          SHM01940
      READ 510,NRHP,NHPT                                                SHM01950
      PRINT 510, NRHP,NHPT                                              SHM01960
  510 FORMAT(I5,F10.5)                                                  SHM01970
      IF(NRHP .EQ.0) GO TO 124                                          SHM01980
      DO 123 KRD=1, NRHP                                                SHM01990
      READ 90, RHPD(KRD),RHPH(KRD),RHPF(KRD)                            SHM02000
   90 FORMAT(2I5,F10.5)                                                 SHM02010
  123 WRITE(6,5) KRD,NHPT,RHPD(KRD),RHPH(KRD),RHPF(KRD)                 SHM02020
   5  FORMAT(//5X,'RECORDED HYDROGRAPH',I3/10X,'HYDROGRAPH INTERVAL =', SHM02030
     1F5.2,1X,5HHOURS/10X,'CALENDAR DAY OF PEAK =',I5,5X,'HOUR OF DAY=' SHM02040
     2,I4,5X,'PEAK FLOW =',F8.1,1X,3HCFS)                               SHM02050
C   INITIALIZE PRECIPITION DATA ARRAYS                                  SHM02060
 124  DO 125 DAY = 1,366                                                SHM02070
      DRGPM(DAY)=RGPMB                                                  SHM02080
      DSSF(DAY)=0.0                                                     SHM02090
      DRSGP(DAY) =0.0                                                   SHM02100
      DO 125 HOUR = 1,24                                                SHM02110
  125 DRHP(DAY,HOUR) =0.0                                               SHM02120
C READ AUXILIARY RAIN GAGE DAILY TOTALS                                 SHM02130
      READ 500,NSGRD                                                    SHM02140
      IF(NSGRD .EQ. 0) GO TO 127                                        SHM02150
```

```
      READ 510,SGRT,WSG
      IF(CONOPT(3).EQ.1)READ  90,SGRT2,SGMD,WSG2
      DO 126 KRD = 1,NSGRD
       READ 103, DRSGP(ISGRD)
      READ 500,ISGRD
  126 DRSGP(ISGRD) = 0.03937*DRSGP(ISGRD)
C READ RECORDING RAIN GAGE HOURLY TOTALS
  127 READ 500,IWBG,YEAR,MONTH,DATE,CN
C  PUNCH NO NUMBERS AFTER CN ON YEAR .EQ. 98 CARD
      IF(YEAR .GE. 98) GO TO 130
      HRF =12*(CN-1) +1
      HRL =12*(CN-1) + 12
      DAY = MEDCY(MONTH) + DATE + 122
      IF(DAY .GT. DPY) DAY= DAY-DPY
      DO 2000 IJK = 1,12
      IF (DAY .GT. MEDCY(IJK)) GO TO 2000
      MONTH = IJK - 1
      GO TO 2050
 2000 CONTINUE
 2050 CONTINUE
       READ 1003,(DRHP(DAY,HOUR),HOUR=HRF,HRL)
      DO 1291 HOUR= HRF,HRL
 1291 DRHP(DAY,HOUR) = 0.03937*DRHP(DAY,HOUR)
 1003 FORMAT(12F5.2)
      IF(DPY .NE. 366 .OR. MONTH .NE. 2 .OR. DATE .NE. 29) GO TO 127
      DO 129 HOUR=HRF,HRL
      DRHP(366,HOUR) =DRHP(60,HOUR)
  129 DRHP(60,HOUR) =0.0
      GO TO 127
C  CALCULATE PRECIPITAION WEGHTING FACTORS
  130 IF(NSGRD .EQ. 0) GO TO 137
      PDAY = 274
      RDPT =0.0
      DAY =274
  131 EHSGD =SGRT
      IF(SGRT.EQ. 0) EHSGD =24
      EHSGDF =EHSGD
  132 CONTINUE
      DO 136 HOUR = 1,24
      RDPT =RDPT +DRHP(DAY,HOUR)
      IF(HOUR .NE. EHSGD) GO TO 136
      IF(RDPT .LE. 0.0) GO TO 133
      IF(SGRT .EQ. 0) PDAY =DAY
      DRGPM (PDAY) =(DRSGP(DAY)*WSG +RDPT*(1.0-WSG))/RDPT
      IF(CONOPT(1) .NE. 0) DPET(PDAY) =0.5*DPET(PDAY)
      IF(SGRT .NE.0) PDAY =DAY
      RDPT =0.0
      GO TO 136
  133 IF(DRSGP(DAY) .LE. 0.0) GO TO 135
      DO 134 KHOUR =1,EHSGD
  134 DRHP(DAY,KHOUR) =(WSG*DRSGP(DAY))/EHSGDF
  135 IF(SGRT .NE. 0) PDAY=DAY
  136 CONTINUE
      CALL DAYNXT(DAY,DPY)
```

```
      IF(DAY .EQ. 274) GO TO 137                                        SHM02700
      IF(CONOPT(3) .EQ.0) GO TO 132                                     SHM02710
      IF(DAY .NE. SGMD) GO TO 132                                       SHM02720
      WSG =WSG2                                                         SHM02730
      SGRT = SGRT2                                                      SHM02740
      GO TO 131                                                         SHM02750
C   ADJUST RAINFALL ANOMALIES                                           SHM02760
  137 MXTRH =2*NBTRI                                                    SHM02770
      IF(CONOPT(2) .EQ. 0) MXTRH = (2*NBTRI -1)/4 +1                    SHM02780
      NATRH =MXTRH/2                                                    SHM02790
      IF(NFTR .GE. 2) GO TO 138                                         SHM02800
      IF(NATRH .LT. 12) CALL PRECHK(DRGPM,DRHP,DRSF,VWIN,SGRT,NATRH)    SHM02810
C   SET INITIAL VALUES OF VARIABLE PARAMETERS TO BE OPTIMIZED           SHM02820
      LZC =12.0                                                         SHM02830
      BMIR = 1.2                                                        SHM02840
        SUZC  = 1.3                                                     SHM02850
      ETLF = 0.25                                                       SHM02860
      BUZC =1.50                                                        SHM02870
      SIAC =0.90                                                        SHM02880
      BIVF =0.90                                                        SHM02890
  138 IF(NFTR .EQ.3) GO TO 139                                          SHM02900
      SRX =0.98                                                         SHM02910
      NCTRI =NBTRI                                                      SHM02920
      CSRX =SRX                                                         SHM02930
      FSRX =SRX                                                         SHM02940
      CALL RECESS(DRSF,DPY,BFRC,IFRC,AREA,RSBD,RSBIF,NRS,RSBBF)         SHM02950
      IF(IFRC.GE.0.3)GO TO 139                                          SHM02960
      WRITE(6,6) IFRC                                                   SHM02970
    6 FORMAT(/10X,'REJECTED IFRC =',F8.4)                               SHM02980
      IFRC =0.1                                                         SHM02990
      BIVF =0.0                                                         SHM03000
  139 IF(NFTR.GE.2)READ 103,LZC,BMIR,SUZC,ETLF,BUZC,SIAC,BIVF,LZS       SHM03010
      IF(NFTR.EQ.3)READ 540,CSRX,FSRX,NCTRI,CHCAP,IFRC,BFRC             SHM03020
  540 FORMAT(2F10.5,I5,3F10.5)                                          SHM03030
  140 BFHRC =BFRC**(1.0/24.0)                                           SHM03040
      BFRL =-ALOG(BFHRC)                                                SHM03050
      CALL FIXTRI(CTRI,BTRI,NBTRI,NCTRI)                                SHM03060
      TRIP =NFTR                                                        SHM03070
      SRX =CSRX                                                         SHM03080
      KHYD =1                                                           SHM03090
      LSHP = .FALSE.                                                    SHM03100
      DO 141 KIA = 1,5                                                  SHM03110
      KPSH(KIA) =0                                                      SHM03120
  141 HBF(KIA) =0.0                                                     SHM03130
C    POINT OF RETURN FOR NEW TRIP                                       SHM03140
  142 IF(KRC .LE. 5) FTX =1.0                                           SHM03150
      IF(DPY .EQ . 366) MEDWY(5) =366                                   SHM03160
      PPH =1.0                                                          SHM03170
      IF(. NOT. LRC) PPH =3.0                                           SHM03180
      IF(TRIP .NE. 1) PPH= 4.0                                          SHM03190
      IPPH =PPH                                                         SHM03200
      FHPP =1.0/PPH                                                     SHM03210
      IFPRC =IFRC**(FHPP/24.0)                                          SHM03220
      IFRL =-ALOG(IFPRC)                                                SHM03230
```

```
      VINTCR =FHPP*VINTMR
      NCTRH =NCTRI
      IF(CONOPT(2) .EQ. 0) NCTRH =(NCTRI -1)/4 +1
C  DETERMINE STORM HOURS FOR ADJUSTING HYDROGRAPH SHAPE VARIABLES
      IF(NRHP .NE. 0  .AND. TRIP .EQ.2) CALL STRHRS(RHPD,RHPH,IDYB,
     1   IDYE,IHRB,IHRE,NHPT,MXTRH,DPY,NRHP,IBTPR)
      HSE =0.0
      NRTRI =0
      PEAI =0.0
      SPIF =0.0
      OFUS=0.0
      OFUSIS =0.0
      RHFO=0.0
      URHF  =0.0
      AMIF =0.0
      AMNET =0.0
      AMPET =0.0
      AMPREC =0.0
      AMBF =0.0
      AMSE =0.0
      KRS =1
      KDRS =400
      UZS =0.0
      IFS =0.0
      IF(NFTR .GE. 2) GO TO 145
      IF(KRC .NE. 1) GO TO 143
      BYLZS =6.00
      LZS =BYLZS
      GO TO 145
  143 IF(EMLZS(11) .LT. LZS) LZS =EMLZS(11)
      LZS =LZS*LZC/PLZC
      IF(LLZC) LZS =     LZC-(LZC-LZS)*(SATFV/RATFV  )
      IF(ABS(FTX -1.0) .LT. 0.02) GO TO 144
      LZS= FTX*BBYLZS*LZC/BLZC
      IF(LRC .AND.(LZC-LZS).LT. 2.0) LZC = LZS + 2.0
  144 IF(TRIP .EQ. 3 .OR. KFFC .EQ. 1) LZS = BBYLZS
      KFFC=0
  145 OCT1BF = 0.05*TMRTF(1)
      IF(DRSF(274) .LT. 0.05*TMRTF(1))OCT1BF = DRSF(274)
      IF(DRSF(276) .LT. OCT1BF*BFRC**2) OCT1BF = DRSF(276)/BFRC**2
      BYGWS = OCT1BF/(WCFS*BFRL*SQRT(BFRC))
       GWS =BYGWS
       BYLZS =LZS
       BFNX =GWS*BFRL
        TFCFS =BFNX*WCFS
       WRITE(6,7) TRIP,LZC,BMIR,SUZC,ETLF,BUZC,SIAC,BIVF,BFRC,IFRC,
     1 CSRX,FSRX,NCTRI,CHCAP
    7  FORMAT(1H1,3X,'TRIAL RUN NUMBER',I3/5X,'PARAMETER VALUES'/10X,
     1  5HLZC =,3X,F8.4,2X,6HBMIR =,2X,F8.4,2X,6HSUZC =,2X,F8.4,2X,
     2   6HETLF =,2X,F8.4,2X,6HBUZC =,2X,F8.4,2X,6HSIAC =,2X,F8.4/10X,
     3   6HBIVF =,2X,F8.4,2X,6HBFRC =,2X,F8.4,2X,6HIFRC =,2X,F8.4,2X,
     4   6HCSRX =,2X,F8.4,2X,6HFSRX =,2X,F8.4,2X,7HNCTRI =,1X,I8/10X,
     5   7HCHCAP =,1X,F8.0)
       WRITE(6,8) LZS,GWS
```

```
  8    FORMAT(/5X,'INITIAL MOISTURE STORAGES,  LZS =',F9.4,5X,'GWS =',
     1   F9.4)
       AETX =24.0*EPAET/365.0
        AEX96 =1.2*AETX
       AEX90 =0.3*AETX
       SIAM =1.2**SIAC
      UZC=SUZC*AEX90+BUZC*EXP(-2.7*LZS/LZC)
      IF(UZC.LT.0.25)UZC=0.25
       MONTH =1
       MDAY = 273
       IF(TRIP .EQ. 1) GO TO 147
 146   WRITE(6,9) (TITLE(KTA), KTA=1,20)
   9   FORMAT(25X,20A4)
        WRITE(6,10) YR1,YR2
  10 FORMAT(03X,61HOPTIMIZATION OF MODEL INPUT PARAMETERS BASED ON WATE
     1R YEAR 19,I2,1H-,I2)
       WRITE(6,11)
  11 FORMAT(5H JUNE)
C    BEGIN DAY LOOP
 147   DAY =274
 148   CONTINUE
       IF(TRIP .NE. 1) GO TO 149
      KDRS = KDRS +1
       IF(RSBD(KRS) .NE. DAY) GO TO 149
       KDRS =1
       KRS =KRS +1
 149   CONTINUE
       ADIF =0.0
       ADBF =0.0
       TDSF =0.0
       PET =DPET(DAY)
       IF(CONDPT(1) .NE. 2) PET= PET*EPCM(MONTH)
       PETU =PET
       TFMAX =0.0
       DO 190 HOUR =1,24
       IF(TRIP .NE. 2) GO TO 152
C    LOGICAL VARIABLE 'LSHP'  SET TRUE DURING DURATION OF RECORDED HYDRO-
C    GRAPH SO SYNTHESIZED DATA MAY BE SAVED DURING CORRESPONDING PERIOD
       IF(KHYD .GT.NRHP) GO TO 152
      IF(IDYB(KHYD) .EQ. DAY .AND. IHRB(KHYD) .EQ. HOUR) LSHP = .TRUE.
       IF(KHYD .GE. NRHP) GO TO 150
       IF(IDYB(KHYD+1).EQ. DAY .AND. IHRB(KHYD+1) .EQ.HOUR) KHYD=
     1   KHYD+1
 150 IF(IDYE(KHYD) .NE. DAY .OR.IHRE(KHYD) .NE. HOUR) GO TO 151
      KHYD = KHYD + 1
       LSHP = .FALSE.
 151   IF( .NOT. LSHP) GO TO 152
       KPSH(KHYD)= KPSH(KHYD) +1
       IF(KPSH(KHYD) .LT. 171) GO TO 152
       WRITE(6,12)
 12   FORMAT(5X,'FLOOD HYDROGRAPH ARRAY EXCEEDED, SHORTEN NHPT OR SHIFT
     1TO HOURLY ROUTING')
       GO TO 228
 152   CONTINUE
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      IF((NSGRD .EQ.0) .AND. (DRHP(DAY,HOUR) .NE. 0.0) .AND.(PET .EQ.  SHM04320
     1 PETU) .AND. (CONOPT(1) .NE. 0)) PET = 0.5*PET                  SHM04330
  153 IF(HOUR .EQ. SGRT+1) RGPM =DRGPM(DAY)                           SHM04340
      IF(HOUR .EQ. 9) HSE =(FWTR*PET)/12.0                            SHM04350
      IF(HOUR .EQ. 21) HSE =0.0                                       SHM04360
      PRH =RGPM*DRHP(DAY,HOUR)                                        SHM04370
      AMPREC =AMPREC + PRH                                            SHM04380
      ARHF =0.0                                                       SHM04390
C   15 MIN ACCOUTING AND ROUTING LOOP (60 MINUTES USED FOR ROUGH      SHM04400
C     ADJUSTMENT, AND 20 MINUTES FOR FINE ADGUSTMENT IN TRIP 1)       SHM04410
      DO 182 PRD= 1,IPPH                                              SHM04420
      IF(LSHP .AND.CONOPT(2) .EQ. 0.AND. PRD .NE. 1) KPSH(KHYD) =     SHM04430
     1  KPSH(KHYD) +1                                                 SHM04440
      PEBI =0.0                                                       SHM04450
     PPI=0.0                                                          SHM04460
      OFR =0.0                                                        SHM04470
      OFRIS =0.0                                                      SHM04480
      WI =0.0                                                         SHM04490
      WEIFS =0.0                                                      SHM04500
      PEP =FHPP*PRH                                                   SHM04510
      IF(TRIP .GE.2 .AND.LNPR) CALL PREPRD(RGPM,DRHP,DAY,HOUR,DPY,PRD, SHM04520
     1  PEP,PRH)                                                      SHM04530
      IF(PEP .GT.  0.0) GO TO 155                                     SHM04540
      IF(OFUS .GT. 0.0) GO TO 157                                     SHM04550
      IF(IFS .GT. 0.0) GO TO 167                                      SHM04560
      IF(TRIP .EQ. 1) GO TO 181                                       SHM04570
      IF(NRTRI .GT. 0) GO TO 169                                      SHM04580
      TRHF = 0.0                                                      SHM04590
       IF(. NOT. LSHP) GO TO 154                                      SHM04600
      KHPT =KPSH(KHYD)                                                SHM04610
      SSR(KHYD,KHPT) =0.0                                             SHM04620
 154  CONTINUE                                                        SHM04630
      IF(RHFO .GT. 0.0) GO TO 178                                     SHM04640
      GO TO 181                                                       SHM04650
C   RAINFALL UPPER ZONE INTERACTION                                   SHM04660
  155 IF(PEP .GE.VINTCR) GO TO 156                                    SHM04670
      UZS =UZS +PEP*TPLR                                              SHM04680
     VINTCR = VINTCR-PEP                                              SHM04690
      PPI=0.0                                                         SHM04700
      PEBI=0.0                                                        SHM04710
      IF(OFUS .GT.0.0) GO TO 157                                      SHM04720
      GO TO 167                                                       SHM04730
  156 PPI =PEP-VINTCR                                                 SHM04740
      UZS =UZS+VINTCR*TPLR                                            SHM04750
      VINTCR =0.0                                                     SHM04760
      LZSR =LZS/LZC                                                   SHM04770
      UZC =SUZC*AEX9D +BUZC*EXP(-2.7*LZSR)                            SHM04780
      IF(UZC .LT. 0.25) UZC =0.25                                     SHM04790
      UZRX= 2.0*ABS(UZS/UZC-1.0) +1.0                                 SHM04800
      FMR =(1.0/(1.0 +UZRX))**UZRX                                    SHM04810
      IF(UZS .GT. UZC) FMR =1.0-FMR                                   SHM04820
      PEBI=PPI*FMR                                                    SHM04830
      UZS =UZS+PPI-PEBI                                               SHM04840
C   LOWER ZONE AND GROUNDWATER INFILTRATION                           SHM04850
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157  LZSR =LZS/LZC                                                          SHM04860
     EID =4.0*LZSR                                                          SHM04870
     IF(LZSR .LE.1.0) GO TO 158                                             SHM04880
     EID =4.0+ 2.0*(LZSR-1.0)                                               SHM04890
     IF(LZSR .LE.2.0) GO TO 158                                             SHM04900
     EID= 6.0                                                               SHM04910
     CMIR =FHPP*SIAM*BMIR/(2.0**EID)                                        SHM04920
158  PEBI =PEBI +OFUS                                                       SHM04930
     CIVM =BIVF*2.0**LZSR                                                   SHM04940
     IF(CIVM .LT. 1.0)CIVM =1.0                                             SHM04950
     PEAI =PEBI*PEBI/(2.0*CMIR*CIVM)                                        SHM04960
    WI = PEBI*PEBI/(2.0*CMIR)                                               SHM04970
    IF(PEBI .GE. CMIR) WI= PEBI-0.5*CMIR                                    SHM04980
     IF(PEBI .GE. CMIR*CIVM) PEAI =PEBI -0.5*CMIR*CIVM                      SHM04990
     WEIFS =WI-PEAI                                                         SHM05000
    IF((PEAI-OFUS) .GT.0.0) GO TO 159                                       SHM05010
     EQD =(OFUS +PEAI)/2.0                                                  SHM05020
     GO TO 160                                                              SHM05030
159 EQD = EQDF*((PEAI-OFUS)**0.6)                                           SHM05040
160 IF((OFUS+PEAI)  .GT. (2.0*EQD)) EQD =0.5* (OFUS + PEAI)                 SHM05050
    IF((OFUS+PEAI) .LE. 0.001) GO TO 161                                    SHM05060
    OFR=FHPP*OFRF*(((OFUS +PEAI)*0.5)**1.67)*((1.0 +.6*((OFUS +             SHM05070
   1  PEAI)/(2.0*EQD))**3.0)**1.67)                                         SHM05080
    IF(OFR .GT. (0.75*PEAI)) OFR =0.75*PEAI                                 SHM05090
161 IF(FIMP .EQ. 0.0) GO TO 165                                             SHM05100
162 PEIS =PPI +OFUSIS                                                       SHM05110
    IF((PEIS-OFUSIS) .GT.0.0) GO TO 163                                     SHM05120
    EQDIS =(OFUSIS + PEIS)/2.0                                              SHM05130
    GO TO 164                                                               SHM05140
163 EQDIS=EQDFIS*((PEIS -OFUSIS)**0.6)                                      SHM05150
164 IF((OFUSIS+PEIS) .GT. (2.0*EQDIS)) EQDIS =0.5*(OFUSIS +PEIS)            SHM05160
    IF((OFUSIS +PEIS) .LE.0.01) GO TO 165                                   SHM05170
    OFRIS =FHPP*OFRFIS*((( OFUSIS +PEIS)*0.5)**1.67)*((1.0 +0.6*((          SHM05180
   1  OFUSIS +PEIS)/(2.0*EQDFIS))**3.0)**1.67)                              SHM05190
    IF(OFRIS .GT. PEIS) OFRIS =PEIS                                         SHM05200
165 OFUSIS =PEIS-OFRIS                                                      SHM05210
    OFUS =PEAI -OFR                                                         SHM05220
    IF(OFUS.GE.0.001)GO TO 166                                              SHM05230
    LZS =LZS +OFUS                                                          SHM05240
    OFUS=0.0                                                                SHM05250
    OFRIS =OFRIS +OFUSIS                                                    SHM05260
    OFUSIS=0.0                                                              SHM05270
166 LZRX =1.5*ABS(LZS/LZC -1.0) +1.0                                        SHM05280
    FMR =(1.0/(1.0 +LZRX))**LZRX                                            SHM05290
    IF(LZS .LT. LZC) FMR = 1.0- FMR*(LZS/LZC)                               SHM05300
    PLZS=FMR*(PEBI-WI)                                                      SHM05310
    PGW=(1.0-FMR) *(PEBI -WI)*( 1.0 -SUBWF)*FPER                            SHM05320
    GWS=GWS+PGW                                                             SHM05330
    LZS =LZS +PLZS                                                          SHM05340
    IFS=IFS+WEIFS*FPER                                                      SHM05350
167 SPIF =IFRL*IFS                                                          SHM05360
    AMIF =AMIF+SPIF                                                         SHM05370
    ADIF=ADIF+SPIF                                                          SHM05380
    IFS =IFS-SPIF                                                           SHM05390
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      IF(IFS.GE.0.0001) GO TO 168
      LZS=LZS+IFS
      IFS=0.0
  168 UHFA(1) =FPER*OFR +PPI*FWTR +FIMP*OFRIS +SPIF
      IF(TRIP .NE. 1) GO TO 169
      ARHF =ARHF +UHFA(1)
      GO TO 181
C  ROUTING
  169 IF(CONOPT (2) .NE. 1) GO TO 170
      URHF =URHF +0.25*UHFA(1)
      IF(PRD.NE. 4) GO TO 178
      UHFA(1)=URHF
C  SAVES SYNTHESIZED DIRECT RUNOFF AND INTER FLOW ENTERING STREAM DURING
C     DURATION OF RECORDED HYDROGRAPH
  170 IF( .NOT. LSHP) GO TO 171
      KHPT =KPSH(KHYD)
      IF(CONOPT(2) .EQ.1) SSR(KHYD,KHPT) =4.0*URHF*WCFS
      IF(CONOPT(2) .EQ. 0)SSR(KHYD,KHPT) =4.0*UHFA(1)*WCFS
  171 CONTINUE
      TRHF = 0.0
      KTRI =NCTRI
  172 URHF =UHFA(KTRI)
      IF(URHF .LE. 0.0) GO TO 174
  173 TRHF =TRHF +URHF*CTRI(KTRI)
      UHFA(KTRI + 1) = URHF
      GO TO 175
  174 UHFA(KTRI +1) =0.0
  175 KTRI =KTRI -1
      IF(KTRI .GE. 1) GO TO 172
  176 IF(URHF .LE. 0.0) GO TO 177
      NRTRI =NCTRI
  177 NRTRI =NRTRI -1
      UHFA(1) =0.0
      URHF =0.0
  178 IF(TRIP .LE.2) GO TO 179
      IF(TFCFS .LE. 0.5*CHCAP) SRX = CSRX
      IF((TFCFS .GT. 0.5*CHCAP) .AND. (TFCFS .LT. 2.0*CHCAP)) SRX = CSRX
     1  +(FSRX -CSRX)*((TFCFS-0.5*CHCAP)/(1.5*CHCAP))**3
      IF(TFCFS .GT.2.0*CHCAP) SRX =FSRX
  179 RHF1 =TRHF-SRX*(TRHF-RHF0)
      RHF0 =RHF1
      IF(RHF0.LT. RHFMC) RHF0 =0.0
      TFCFS =(4.0*RHF1 +CBF-HSE)*WCFS
      IF(TFCFS .LE.TFMAX) GO TO 180
      PRDF =PRD
      TDFP24 =HOUR
      IF(PRD .LE.3) TDFP24=( TDFP24-1.0) + 0.15*PRDF
      TFMAX =TFCFS
  180 ARHF =ARHF + RHF1
  181 IF(VINTCR .LT. FHPP*VINTMR) VINTCR =VINTCR +DPET(DAY)/(24.0/
     1  FHPP)
  182 CONTINUE
C  END OF 15 MINUTE LOOP
C  ADDING GROUNDERWATER FLOW
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 183 CBF =GWS*BFRL                                                    SHM05940
     IF(KHYD .GT. NRHP) GO TO 184                                     SHM05950
     IF(LSHP .AND. (HBF(KHYD) .EQ. 0.0)) HBF(KHYD) = CBF*WCFS         SHM05960
 184 GWS =GWS-CBF                                                     SHM05970
     AMBF =AMBF +CBF                                                  SHM05980
     THGR =ARHF +CBF                                                  SHM05990
C  EVAPORATION FROM STREAM SURFACE                                    SHM06000
 185 IF(HSE .GT. THGR) HSE =THGR                                      SHM06010
     IF(CBF .GT. HSE) ADBF =ADBF +CBF -HSE                            SHM06020
     AMSE =AMSE+HSE                                                   SHM06030
     THSF(HOUR) = (THGR -HSE)*WCFS                                    SHM06040
     IF(TFMAX .LE.0.0)TFMAX =THSF(HOUR)                               SHM06050
     TDSF = TDSF + THSF(HOUR)                                         SHM06060
C  DRAINING OF UPPER ZONE STORAGE                                     SHM06070
     UZINFX =(UZS/UZC) -(LZS/LZC)                                     SHM06080
     IF(UZINFX .LE. 0.0) GO TO 186                                    SHM06090
     LZSR =LZS/LZC                                                    SHM06100
     UZINLZ =0.003*BMIR*UZC*UZINFX**3.0                               SHM06110
     IF(UZINLZ .GT.UZS)  UZINLZ =UZS                                  SHM06120
     UZS =UZS -UZINLZ                                                 SHM06130
     LZRX =1.5*ABS(LZSR -1.0)+1.0                                     SHM06140
     FMR =(1.0/(1.0 +LZRX))**LZRX                                     SHM06150
     IF(LZS .LT. LZC) FMR=1.0-FMR*LZSR                                SHM06160
     PGW =(1.0-FMR)*UZINLZ*(1.0 -SUBWF)*FPER                          SHM06170
     PLZS=FMR*UZINLZ                                                  SHM06180
     LZS =LZS +PLZS                                                   SHM06190
     GWS =GWS +PGW                                                    SHM06200
C  4 PM ADJUSTMENTS OF VARIUS VALUES                                  SHM06210
 186 IF(HOUR .NE. 16) GO TO 190                                       SHM06220
     AEX90 =0.9*(AEX90 +PET)                                          SHM06230
     AEX96 =0.96*(AEX96 +PET)                                         SHM06240
C  INFILTRATION CORRECTION                                            SHM06250
     SIAM =(AEX96/AETX)**SIAC                                         SHM06260
     IF(SIAM .LT. 0.33) SIAM =0.33                                    SHM06270
     IF(PET .EQ. 0.0) GO TO 190                                       SHM06280
C  EVAP-TRANS LOSS FROM GROUND  WATER                                 SHM06290
     GWET =GWS*GWETF*PET*FPER                                         SHM06300
     GWS =GWS-GWET                                                    SHM06310
     AMPET =AMPET +PET                                                SHM06320
     IF(PET .GE. UZS) GO TO 187                                       SHM06330
     UZS =UZS -PET                                                    SHM06340
     AMNET =AMNET +PET                                                SHM06350
     GO TO 190                                                        SHM06360
 187 PET = PET-UZS                                                    SHM06370
     AMNET =AMNET + UZS                                               SHM06380
     UZS =0.0                                                         SHM06390
     LZSR = LZS/LZC                                                   SHM06400
     IF(PET .GE. ETLF*LZSR) GO TO 188                                 SHM06410
     SET = PET*(1.0- PET/(2.0*ETLF*LZSR))                             SHM06420
     GO TO 189                                                        SHM06430
 188 SET =0 .5*ETLF*LZSR                                              SHM06440
 189 LZS =LZS-SET                                                     SHM06450
     AMNET =AMNET +SET                                                SHM06460
 190 CONTINUE                                                         SHM06470
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C   END OF HOUR LOOP
      DSSF(DAY) =TDSF/24.0
      IF(TRIP.EQ. 1) GO TO 192
      IF(TFMAX .LE. RMPF) GO TO 192
      IF(DAY .EQ. 366) MDAY =337
      DATE =MOD(DAY,MDAY)
      WRITE(6,13) DATE, (THSF(HOUR),HOUR=1,12)
   13 FORMAT(1H/,1X/,1X,I4,2X,2HAM,1X,6F8.1,3X,6F8.1)
      WRITE(6,14) (THSF(HOUR),HOUR=13,24) , DSSF(DAY)
   14 FORMAT(1H/,6X,2HPM,1X,6F8.1,3X,7F8.1)
      IF(TDFP24 .LT . 12.0) GO TO 191
      TDFP12 =TDFP24 -12.0
      WRITE(6,15) TFMAX, TDFP12
  15  FORMAT(1H/,10X,'MAXIMUM=',F8.1,2X,'C.F.S.',5X,'TIME',3X,F5.2,2X,
     1  4HP.M.)
      GO TO 192
  191 WRITE(6,16) TFMAX,TDFP24
   16 FORMAT(1H/,10X,8HMAXIMUM=,F8.1,2X,6HC.F.S.,5X,4HTIME,3X,F5.2,2X,
     1  4HA.M. )
  192 CONTINUE
      IF(TRIP .EQ. 1 .AND. .NOT. LRC .AND. KDRS .LE. 3 .AND. IFRC .GT.
     1  0.1) SIFRS(KDRS,KRS-1) = ADIF*VWIN
      IF(TRIP .EQ. 1  .AND. KDRS .LE. 3) SBFRS(KDRS,KRS-1) =ADBF*VWIN
C   MONTHLY SUMMARY STORAGE
      IF(DAY .NE. MEDWY(MONTH)) GO TO  206
      TMPREC(MONTH) = AMPREC
      AMPREC =0.0
      TMBF(MONTH) = AMBF
      AMBF =0.0
      TMIF(MONTH) = AMIF
      AMIF =0.0
      TMSE(MONTH) =AMSE
      AMSE =0.0
      TMPET(MONTH) = AMPET
      AMPET =0.0
      TMNET(MONTH) =AMNET
      AMNET =0.0
      EMGWS(MONTH) = GWS
      UZC=SUZC*AEX90 +BUZC*EXP(-2.7*LZS/LZC)
      IF(UZC .LT. 0.25) UZC =0.25
      EMUZC(MONTH)=UZC
      EMUZS(MONTH) =UZS
      EMSIAM(MONTH) =SIAM
      EMLZS(MONTH) =LZS
      EMIFS(MONTH) =IFS
      IF(MONTH .EQ. 5) MEDWY(5) =59
      MDAY =MEDWY(MONTH)
      IF(TRIP .EQ. 1) GO TO 205
  193 GO TO (194,195,196,197,198,199,200,201,202,203,204,
     1   205),MONTH
  194 WRITE(6,17)
   17 FORMAT(1H/,4HJULY)
      GO TO 205
  195 WRITE(6,18)
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   18 FORMAT(1H/,6HAUGUST)
      GO TO 205
  196 WRITE(6,19)
   19 FORMAT(1H/,9HSEPTEMBER)
      GO TO 205
 197  WRITE(6,20)
   20 FORMAT(1H/,7HOCTOBER)
      GO TO 205
  198 WRITE(6,21)
   21 FORMAT(1H/,8HNOVEMBER)
      GO TO 205
  199 WRITE(6,22)
   22 FORMAT(1H/,8HDECEMBER)
      GO TO 205
  200 WRITE(6,23)
   23 FORMAT(1H/,7HJANUARY)
      GO TO 205
 201  WRITE(6,24)
   24 FORMAT(1H/,8HFEBRUARY)
      GO TO 205
 202  WRITE(6,25)
   25 FORMAT(1H/,5HMARCH)
       GO TO 205
 203  WRITE(6,26)
   26 FORMAT(1H/,5HAPRIL)
      GO TO 205
 204  WRITE(6,27)
   27 FORMAT(1H/,3HMAY)
 205  MONTH =MONTH +1
C   END OF DAY LOOP
 206  CALL DAYNXT(DAY,DPY)
      IF(DAY .NE.274) GO TO 148
      IF(TRIP .NE. 2) GO TO 208
C   ADJUST BASE FLOW FOR AVERAGE VALUE DURING STORM
      IF(NRHP .EQ.  0) GO TO 208
      DO 207 KHYD =1,NRHP
      DAY =IDYB(KHYD)
      IF(DSSF(DAY) .GT. HBF(KHYD)) GO TO  207
      HBF(KHYD) =(HBF(KHYD) +DSSF(DAY))/2.0
 207  CONTINUE
  208 IF(TRIP .NE. 1) WRITE(6,28)  (TITLE(KTA), KTA=1,20,1)
  28  FORMAT(1H1,25X,20A4)
C   ANNUAL  SUMMARY
      APREC = 0.0
      ABFV=0.0
      ASEV=0.0
      ANET=0.0
      APET=0.0
      AIFV = 0.0
      DO 209 MONTH =1,12
      APREC =APREC  +TMPREC(MONTH)
      ABFV=ABFV  +TMBF(MONTH)
      ASEV=ASEV+ TMSE(MONTH)
      ANET=ANET  +TMNET(MONTH)
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      APET=APET +TMPET(MONTH)
  209 AIFV=AIFV +TMIF(MONTH)
      WRITE(6,29)
   29 FORMAT(1H///44X,23HSYNTHESIZED       FLOWS)
  210 IF(TRIP .EQ. 1) WRITE(6,30)
   30 FORMAT(//5X,'SUMMARY WHILE OPTIMIZING VOLUME VARIABLES')
  211 CALL DAYSUM(DSSF,MEDCY,DPY,SATFV,TMSTF)
      IF(TRIP .EQ. 1) GO TO 212
      CALL DAYOUT(DSSF,MEDWY,DPY)
  212 WRITE(6,31) (TMSTF(KWD), KWD=1,12),SATFV
   31 FORMAT(1X, 9HSYNTHETIC,3X,12F8.1,2X,F10.1,2X,3HSFD )
      DO 213 MONTH =1,12
  213 TMSTFI(MONTH)= TMSTF(MONTH)/VWIN
      SATFVI =SATFV/VWIN
      WRITE(6,32) (TMSTFI(KWD) ,KWD=1,12),SATFVI
   32 FORMAT(1X,5HTOTAL,8X,12F8.3,4X,F7.3,2X,6HINCHES)
      DO 214 MONTH =1,12
      TMOF(MONTH) =TMSTFI(MONTH)-TMIF(MONTH)-TMBF(MONTH) +
     1  TMSE(MONTH)
  214 IF(TMOF(MONTH) .LT. 0.0) TMOF(MONTH)=0.0
      AOFV=SATFVI-AIFV-ABFV +ASEV
      IF(AOFV .LT.0.0) AOFV=0.0
      WRITE(6,33) (TMOF(KWD), KWD=1,12), AOFV
   33 FORMAT(1X,'OVERLAND',5X,12F8.3,4X,F7.3,2X,'INCHES')
      WRITE(6,34) (TMIF(KWD), KWD=1,12),AIFV
   34 FORMAT(1X,9HINTERFLOW,4X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,35) (TMBF(KWD), KWD=1,12),ABFV
   35 FORMAT(1X,4HBASE,9X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,36) (TMSE(KWD), KWD=1,12), ASEV
   36 FORMAT(1X,9HSTRM EVAP,4X,12F8.3,4X,F7.3,2X,6HINCHES)
      WRITE(6,37) (TMPREC(KWD), KWD=1,12),APREC
   37 FORMAT( 1X,6HPRECIP,7X,12F8.2,3X,F8.2,2X,6HINCHES)
      WRITE(6,38) (TMNET(KWD), KWD=1,12),ANET
   38 FORMAT(1X,'EVP/TRAN-NET',2X,12F8.3,3X,F7.3,2X,'INCHES')
      WRITE(6,39) (TMPET(KWD), KWD=1,12),APET
   39 FORMAT(3X,10H-POTENTIAL,2X,12F8.3,3X,F7.3,2X,6HINCHES)
      WRITE(6,40) (EMUZS(KWD), KWD=1,12)
   40 FORMAT(1X,12HSTORAGES-UZS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,41) (EMLZS(KWD), KWD=1,12)
   41 FORMAT(10X,3HLZS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,42) (EMIFS(KWD), KWD=1,12)
   42 FORMAT(10X,3HIFS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,43) (EMGWS(KWD), KWD=1,12)
   43 FORMAT(10X,3HGWS,2X,12F8.3,12X,6HINCHES)
      WRITE(6,44) (EMUZC(KWD), KWD=1,12)
   44 FORMAT(1X,12HINDICES-UZC ,2X,12F8.3)
      WRITE(6,45) (EMSIAM(KWD), KWD=1,12)
   45 FORMAT(9X,4HSIAM,2X,12F8.3)
      AMBER =(LZS-BYLZS)*FPER+(UZS + IFS + GWS - BYGWS)*(1.0 - FWTR
     1  ) + SATFVI +ANET*FPER+ASEV-APREC
      WRITE(6,46) AMBER
   46 FORMAT(1H/,7HBALANCE,5X,F10.4,2X,6HINCHES)
C  ESTABLISH WHETHER MONTH IS PREDOMINATELY BASE FLOW OR DIRECT RUNOFF
      NOFM=0
```

```
      MONTH1=1
      IF(FTX .LT.  0.95) MONTH1=4
      DO 216 MONTH=1,12
      XMPFT(MONTH) =0.0
      IF(MONTH .LT.MONTH1) GO TO 216
       IF(TMSTFI(MONTH) .GT. 0.001) GO TO 215
      XMPFT(MONTH)=1.0
      GO TO 216
 215  IF(TMBF(MONTH)/TMSTFI(MONTH) .GT. 0.5) XMPFT(MONTH) =1.0
      IF(TMOF(MONTH)/TMSTFI(MONTH) .LT. 0.5) GO TO 216
      NOFM =NOFM+1
      XMPFT(MONTH) =2.0
  216 CONTINUE
C  NATURE OF TRIPS
C     TRIP 1  OPTIMIZE VOLUME VARIABLES WHILE BYPASSING ROUTING
C     TRIP 2 SET FLOOD HYDROGRAPH VARIABLES. CSRX,FSRX,NCTRI,CHCAP
C     TRIP 3  FINAL RUN WITH OPTIMIZED VALUES
  217 IF(TRIP .EQ. 1) GO TO 218
      KRC =MNRC +1
      IF(TRIP .EQ. 2) GO TO 226
      GO TO 228
C SYSTEMATIC ADJUSTMENT OF VOLUME VARIABLES CONVERGING ON OPTIMUM VALUES
  218 KRC=KRC +1
      KBRC =KBRC +1
      PLZC =LZC
      PBMIR =BMIR
      PSUZC =SUZC
      PETLF =ETLF
      PBUZC =BUZC
      PSIAC =SIAC
C  ADJUST FIVE VOLUME VARIABLES. LZC,SUZC,ETLF,BUZC,SIAC
      CALL SETFVP(LZC,SUZC,ETLF,BUZC,SIAC,TMSTF,TMRTF,TMPREC,TMPET,
     1  EMLZS,SSQM,LRC,XMPFT,FTX,NOFM,LBUZC,LETLF,LLZC,APREC,APET)
C  ADJUST INTERFLOW VOLUME CONSTANT DURING FINE ADJUSTMENT PHASE
      FNCTRH =NCTRH
      IF(.NOT. LRC .AND. IFRC .GT. 0.1) CALL SETBIV(BIVF,NRS,IFRC,RSBIF,
     1  SIFRS,FNCTRH)
C  ADJUST INFILTRATION RATE CONSTANT BMIR
      IF(.NOT. LBMIR) GO TO 219
      BMIR =0.9*BMIR
      GO TO 220
  219 IF(ABS(FTX-1.0) .GT. 0.02 .AND. KRC.GT. 5) IFT =2
      CALL SETBMI(BMIR,NRS,BFRC,RSBBF,SBFRS,FNCTRH,IFT)
  220 IF((KRC .GT. 6) .AND. (LZC .GT. 29.0)) LLZC= .TRUE.
      IF((KRC .GT. 6) .AND. (ETLF .GT. 0.59)) LETLF = .TRUE.
      IF((KRC .GT. 6) .AND. (BUZC .GT. 3.9)) LBUZC= .TRUE.
      IF( .NOT. LLZC) GOTO 221
      LZC =PLZC*SATFV/RATFV
      WRITE(6,47) LZC
  47  FORMAT(/2X,'LZC WAS CHANGED TO',F6.2,' BASED ON ANNUAL RUNOFF VOLU
     1ME')
  221 IF(KRC .LT. 6 .OR. BMIR .LT. 20.0) GO TO 222
      LBMIR = .TRUE.
      BMIR= 20.0
```

```
 222  IF(SSSQM .LE. SSQM .AND. ((KRC .GE. MNRC .AND. KBRC .GE. 2) .OR.
    1  (.NOT. LRC))) GO TO  224
      IF(SSSQM .LE. SSQM) GO TO 142
      IF(KRC .GE. MNRC) KRC=KRC-1
      BLZC=PLZC
      BBMIR=PBMIR
      BSUZC=PSUZC
      BETLF= PETLF
      BBUZC=PBUZC
      BSIAC =PSIAC
      SSSQM=SSQM
      BBYLZS=BYLZS
      KBRC=0
      IF(SSQM .LT. 0.15 .AND. LRC) GO TO 223
      GO TO 142
  223 LRC=.FALSE.
      WRITE(6,48)
  48  FORMAT(/5X,'SHIFT TO FINE ADJUSTMENT BEGINNING AT BEST ROUGH ADJUS
    1TMENT POINT')
      SSSQM= 1000.0
      GO TO 225
  224 CONTINUE
      IF(LRC) GO TO 223
      IF(TRIP .GE. NLTR) GO TO 228
      TRIP =TRIP+1
  225 LZC =BLZC
      BMIR = BBMIR
      SUZC = BSUZC
      ETLF = BETLF
      BUZC =BBUZC
      SIAC = BSIAC
      KFFC = 1
      GO TO 142
 226  IF(NRHP .EQ. 0) GO TO 227
C  CORRECT SYNTHESIZED RUNOFF TO RECORDED VOLUMES
      CALL ADJHYD(IDYB,IDYE,IHRB,IHRE,KPSH,DPY,HBF,NRHP,DSSF,DRSF,SSR,
     1  LSHA)
C  ESTABLISH STORM AND OVERALL OPTIMUM VALUES FOR SRX AND NCTRI
      CALL SETHRP(CTRI,BTRI,WCFS,CONOPT(2),HBF,LSHA,SSR,NHPT,KPSH,
     1  IBTPR,SRX,CSRX,FSRX,CHCAP,NRHP,RHPF,NCTRI,NBTRI)
      IF(NCTRI .EQ. 0) GO TO 228
 227  IF(TRIP .GE. NLTR) GO TO 228
      TRIP = TRIP +1
      GO TO 142
 228  CONTINUE
      IF(NSYC .LT. NSYT) GO TO 100
      STOP
      END
      SUBROUTINE ADJHYD(IDYB,IDYE,IHRB,IHRE,KPSH,DPY,HBF,NRHP,DSSF,
     1  DRSF,SSR,LSHA)
C  ADJUSTS SYNTHESIZED FLOW VOLUME TO MATCH RECORDED VOLUME FOR SETTING
C     HYDROGRAPH ROUTTING PARAMETERS
      DIMENSION  IDYB(5),IDYE(5),IHRB(5),KPSH(5),SSR(5,170),
     1  DSSF(366),DRSF(366),HBF(5),LSHA(5),IHRE(5)
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      LOGICAL  LSHA,LSHP                                                SHM09180
      INTEGER  DAY,DPY                                                  SHM09190
      LSHP = .FALSE.                                                    SHM09200
      KRHP = 1                                                          SHM09210
      DAY = 274                                                         SHM09220
  100 CONTINUE                                                          SHM09230
      IF(LSHP) GO TO 102                                                SHM09240
      IF(IDYB(KRHP) .NE. DAY) GO TO 107                                 SHM09250
  101 HTH= IHRB(KRHP)                                                   SHM09260
      HBFM= 1.0                                                         SHM09270
      IF(DSSF(DAY) .LT. HBF(KRHP)) HBFM= 0.0                            SHM09280
      TSHV= (24.0-HTH)*(DSSF(DAY) -HBF(KRHP))*HBFM/24.0                 SHM09290
      HBFM = 1.0                                                        SHM09300
      IF(DRSF(DAY) .LT.HBF(KRHP)) HBFM= 0.0                             SHM09310
      TRHV = (24.0 -HTH)*(DRSF(DAY) -HBF(KRHP))*HBFM/24.0               SHM09320
      IF(IDYE(KRHP) .EQ. DAY) GO TO 104                                 SHM09330
      LSHP = .TRUE.                                                     SHM09340
      GO TO 107                                                         SHM09350
  102 IF(DSSF(DAY) .LT. HBF(KRHP)) GO TO 103                            SHM09360
      TSHV =TSHV + DSSF(DAY) -HBF(KRHP)                                 SHM09370
  103 IF(DRSF(DAY) .LT. HBF(KRHP)) GO TO 104                            SHM09380
      TRHV = TRHV + DRSF(DAY) -HBF(KRHP)                                SHM09390
  104 CONTINUE                                                          SHM09400
      IF(IDYE(KRHP) .NE. DAY) GO TO 107                                 SHM09410
      HTH = IHRE(KRHP)                                                  SHM09420
      TSHV =TSHV -(24.0-HTH)*(DSSF(DAY) -HBF(KRHP))/24.0                SHM09430
      TRHV = TRHV-(24.0 -HTH)*(DRSF(DAY) -HBF(KRHP))/24.0               SHM09440
      LSHP =.FALSE.                                                     SHM09450
      SHM= TRHV/TSHV                                                    SHM09460
      LSHA(KRHP) = .TRUE.                                               SHM09470
      IF(SHM .GT. 8.0 .OR. SHM .LT. 0.125) LSHA(KRHP) = .FALSE.         SHM09480
      IF( .NOT. LSHA(KRHP)) GO TO 106                                   SHM09490
      KPCH =KPSH(KRHP)                                                  SHM09500
      DO 105 KHPT = 1,KPCH                                              SHM09510
  105 SSR(KRHP,KHPT) = SHM*SSR(KRHP,KHPT)                               SHM09520
  106 WRITE(6,1) KRHP,SHM                                               SHM09530
    1 FORMAT(//10X,'VOLUME ADJUSTMENT FACTOR FOR HYDROGRAPH',I2,        SHM09540
     1  'EQUALS',F10.4)                                                 SHM09550
      KRHP = KRHP + 1                                                   SHM09560
      IF(KRHP .GT. NRHP) RETURN                                         SHM09570
      IF(IDYB(KRHP) .EQ. IDYE(KRHP-1)) GO TO 101                        SHM09580
  107 CALL DAYNXT(DAY,DPY)                                              SHM09590
      IF(DAY .NE. 274) GO TO 100                                        SHM09600
      RETURN                                                            SHM09610
      END                                                               SHM09620
      SUBROUTINE DAYSUM(DRSF,MEDCY,DPY,ATFV,TMTFWY)                     SHM09630
C   SUMS DAILY VALUES TO GET MONTHLY AND ANNUAL TOTALS                  SHM09640
      DIMENSION DRSF(366),EMATF(13),MEDCY(12),TMTFCY(12),TMTFWY(12)     SHM09650
      INTEGER DAY,DPY                                                   SHM09660
C   SUM ANNUAL AND CUMULATIVE MONTHLY FLOWS                             SHM09670
      EMATF(1) = 0.0                                                    SHM09680
      ATF = 0.0                                                         SHM09690
      DO 101 DAY = 1,365                                                SHM09700
      ATF =ATF +DRSF(DAY)                                               SHM09710
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      DO 100 KMO = 2,12                                                 SHM09720
 100  IF(DAY .EQ. MEDCY(KMO)) EMATF(KMO) = ATF                          SHM09730
 101  CONTINUE                                                          SHM09740
      EMATF(13) =ATF                                                    SHM09750
      ATFV =ATF +DRSF(366)                                              SHM09760
   CALCULATE MONTHLY FLOWS                                              SHM09770
      DO 102 KMO = 1,12                                                 SHM09780
  102 TMTFCY(KMO) =EMATF(KMO + 1) -EMATF(KMO)                           SHM09790
      TMTFCY(2) = TMTFCY(2) + DRSF(366)                                 SHM09800
   CONVERT MONTHLY FLOWS TO AWATER YEAR ORDER                           SHM09810
      DO 103 KMO =1,9                                                   SHM09820
 103  TMTFWY(KMO+3) =TMTFCY(KMO)                                        SHM09830
      DO 104 KMO = 10,12                                                SHM09840
 104  TMTFWY(KMO-9) = TMTFCY(KMO)                                       SHM09850
      RETURN                                                            SHM09860
      END                                                               SHM09870
      SUBROUTINE FIXTRI(CTRI,BTRI,NBTRI,NCTRI)                          SHM09880
   FIX VALUES OF THE TIME ROUTING INCREMENTS TO MATCH REQUIRED TOTAL    SHM09890
     NUMBER OF VALUES                                                   SHM09900
      DIMENSION AWSBIT(99),BTRI(99),CTRI(99)                            SHM09910
      IF(NCTRI .GT. 99) GO TO 101                                       SHM09920
      IF(NBTRI .NE. NCTRI)  GO TO 102                                   SHM09930
      DO 100 KRD = 1,99                                                 SHM09940
 100  CTRI(KRD) = BTRI(KRD)                                             SHM09950
      RETURN                                                            SHM09960
 101  WRITE(6,1) NCTRI                                                  SHM09970
   1  FORMAT(5X,'NCTRI OF',I5,1X,'EXCEEDS MAXIMUM VALUE OF 99, 99 USED')SHM09980
      NCTRI = 99                                                        SHM09990
 102  DO 103 KIA = 1,99                                                 SHM10000
 103  AWSBIT(KIA) = 0.0                                                 SHM10010
      FNTRI = NCTRI                                                     SHM10020
      KB1 = 0                                                           SHM10030
      KB2 = 1                                                           SHM10040
      KB3 = 0                                                           SHM10050
 104  KB1 =KB1 + 1                                                      SHM10060
      IF(KB1 .GT. NBTRI) GO TO 107                                      SHM10070
      KB4 = 0                                                           SHM10080
      WSBIT = BTRI(KB1)/FNTRI                                           SHM10090
 105  KB4 = KB4 + 1                                                     SHM10100
      IF(KB4 .GT. NCTRI) GOTO 104                                       SHM10110
      AWSBIT(KB2) =AWSBIT(KB2) + WSBIT                                  SHM10120
      KB3 = KB3 +1                                                      SHM10130
      IF(KB3 .LT. NBTRI) GO TO 106                                      SHM10140
      KB3 = 0                                                           SHM10150
      KB2 = KB2 + 1                                                     SHM10160
 106  GO TO 105                                                         SHM10170
 107  DO 108 KB5 = 1,99                                                 SHM10180
 108  CTRI (KB5) = AWSBIT(KB5)                                          SHM10190
      RETURN                                                            SHM10200
      END                                                               SHM10210
      SUBROUTINE PRECHK(DRGPM,DRHP,DRSF,VWIN,SGRT,NATRH)                SHM10220
C   CHECKS PRECIPITATION-STREAMFLOW ANOMALIES AND ADJUSTS PRECIPITATION SHM10230
C     WHERE NECESSARY                                                   SHM10240
       DIMENSION DRGPM(366),DRSF(366),DRHP(366,24)                      SHM10250
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```
      INTEGER DAY,HCUR,SGRT
      AHP = 0.0
      NRHA = 24-NATRH
      RGPM = DRGPM(90)
      DAY=90
      RMWR=1.25
 00   DAY=DAY+1
      IF(DAY .GT.200 .OR.VWIN.GT.750.0) RMWR=2.00
      RFRISE =(DRSF(DAY) -DRSF(DAY-1))/VWIN
      DO 101 HOUR = 1,24
      IF(HOUR .EQ. SGRT+1) RGPM =DRGPM(DAY)
      AHP =AHP + DRHP(DAY,HOUR)*RGPM
      IF(HOUR .NE. NRHA) GO TO 101
      RWRAIN =AHP
      AHP = 0.0
  101 CONTINUE
      IF(RFRISE .GT. RWRAIN .AND.RFRISE .GT. 0.1) GO TO 102
      IF((RWRAIN .GT. RMWR .AND. RFRISE .LT. 0.02*RWRAIN)  .OR. (RWRAIN
     1  .GT. 3.00 .AND. RFRISE .LT. 0.05*RWRAIN)) GO TO 104
      GO TO    108
  102 IF(RWRAIN .GT. 0.05) GO TO 103
      RAA = RFRISE*2.0-RWRAIN +1.0
      DRHP(DAY,13) = RAA
      WRITE(6,1) DAY, RAA
 1    FORMAT(/10X,'FOR DAY',I4,1X,'RAIN ADDED OF',F7.2)
      GO TO 108
  103 RAM =2.0*RFRISE/RWRAIN
      GO TO 105
  104 RAM = 10.0 *RFRISE/RWRAIN
 105  IF(RAM .LT. 0.0) GO TO 108
      WRITE(6,2) DAY,RAM,RWRAIN
 2    FORMAT(/5X,'FOR DAY',I4,1X,'RAIN ADJUSTMENT MULTIPLIER IS',F8.4,
     1  1X,'RECORDED RAIN IS',F7.2)
      DO 106 HOUR = 1,NRHA
  106 DRHP(DAY,HOUR) =DRHP(DAY,HOUR)*RAM
      IF(NATRH .EQ. 0) GO TO 108
      NFRHA =NRHA +1
      DO 107 HOUR =NFRHA,24
  107 DRHP(DAY-1,HOUR) =DRHP(DAY-1,HOUR)*RAM
  108 IF(DAY .NE. 273) GO TO 100
      RETURN
      END
      SUBROUTINE RECESS(DRSF,DPY,BFRC,IFRC,AREA,RSBD,RSBIF,NRS,RSBBF)
C  ESTABLISHES RECESSION SEQUENCES
      DIMENSION DRSF(366),LBFO(20),NDRS(20),RSBBF(20),RSBD(20),
     1  RSBFRC(20),RSBIF(20),RSIFRC(20),RSTF(50,20)
      LOGICAL LBFO
      INTEGER DAY,DPY,RSBD,RSL
      REAL  IFRC
      MRSL = 9
      BFRC = 0.9
      IFRC = 0.05
      FRERS = 0.1*SQRT(AREA)
  100 DO 101 KSD = 1,50
```

```
      DO 101 KRS = 1,20
  101 RSTF(KSD,KRS) = 0.0
      KRS = 0
      DAY = 274
   BEGIN NEW SEQUENCE
  102 IF(KRS .GE. 20) GO TO 109
      KRS =KRS + 1
      KSD = 1
      RSF1 = DRSF(DAY)
      CALL DAYNXT(DAY,DPY)
      IF(DAY .EQ. 274) GO TO 107
      RSF2 =DRSF(DAY)
      RSBD(KRS) = DAY
      IF(RSF2 .LT.(RSF1+FRERS).AND. (RSF2 .GT. 0.4*AREA .OR. RSF2 .GT.
     1  10.0)) GO TO 103
      KRS = KRS - 1
      GO TO 102
  103 RSTF(1,KRS) =RSF2
      RSFM = RSF2
 104  KSD = KSD + 1
      CALL DAYNXT(DAY,DPY)
      IF(DAY .EQ. 274) GO TO 107
      RSFN =DRSF(DAY)
      IF(RSFN .LT. (RSFM +FRERS) .AND. RSFN .GT.  0.0) GO TO 106
      IF(KSD .GE. MRSL) GO TO 102
      NDRS(KRS) =0
      DO 105  KSD = 1,MRSL
  105 RSTF(KSD,KRS) =0.0
      KRS =KRS - 1
      GO TO 102
 106  IF(RSFN .LT. RSFM) RSFM =RSFN
      RSTF  (KSD,KRS) =RSFN
      NDRS(KRS) =KSD
      IF(KSD .GE. 50) GO TO 102
      GO TO 104
  107 IF(KSD .GE. MRSL) GO TO 109
      NTRS =KRS - 1
      DO 108 KSD = 1,MRSL
 108  RSTF(KSD,KRS) = 0.0
      GO TO 110
  109 NTRS = KRS
 110  CONTINUE
      IF(NTRS .GE. 3) GO TO 111
      IF(MRSL . LT. 7) RETURN
      MRSL = 6
      GO TO 100
C  WRITE OUT ESTABLISHED ARRAY OF FLOW SEQUENCES
  111 WRITE(6,1)
  1   FORMAT(/5X,'FLOW SEQUENCES USED TO ESTIMATE RECESSION CONSTANTS')
      DO 113 KRS = 1, NTRS
      NDRSC =NDRS(KRS)
      DO 112 KSD =2,NDRSC
  112 RSTF(KSD-1,KRS) =RSTF(KSD,KRS)
      NDRS(KRS) =NDRS(KRS) - 1
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      NDRSC = NDRSC - 1                                                 SHM11340
      WRITE(6,2) KRS,(RSTF(KSD,KRS),KSD=1,NDRSC)                        SHM11350
    2 FORMAT(/10X,I2,5(10F8.1/12X))                                     SHM11360
113   CONTINUE                                                          SHM11370
 DETERMINE RECESSION CONSTANS FROM EACH SEQUENCE                        SHM11380
114   DO 116 KRS = 1,NTRS                                               SHM11390
      IF((RSTF(1,KRS) .LT. 0.4*AREA) .AND. (RSTF(2,KRS) .GT. 0.8*       SHM11400
     1  (RSTF(1,KRS)))) GO TO 115                                       SHM11410
      LBFO(KRS) = .FALSE.                                               SHM11420
      CALL SET2RC(RSTF,KRS,NDRS(KRS),RSIFRC(KRS),RSBFRC(KRS),LBFO(KRS)) SHM11430
      IF(LBFO(KRS) .OR. RSBFRC(KRS) .GT. 1.2 .OR. RSBFRC(KRS) .LT. 0.6  SHM11440
     1  .OR. RSIFRC(KRS) .GT. 0.8 .OR. RSIFRC(KRS) .LT.(-0.4))GO TO 115 SHM11450
      GO TO 116                                                         SHM11460
15    LBFO(KRS) = .TRUE.                                                SHM11470
      CALL SET1RC(RSTF,KRS,NDRS(KRS),RSBFRC(KRS))                       SHM11480
16    CONTINUE                                                          SHM11490
 CALCULATE WEIGHTED AVERAGE RECESSION CONSTANTS                         SHM11500
      BFRC = 0.0                                                        SHM11510
      IFRC = 0.0                                                        SHM11520
      ABFSL = 0.0                                                       SHM11530
      AIFSL = 0.0                                                       SHM11540
      DO 118 KRS = 1,NTRS                                               SHM11550
      IF(RSBFRC(KRS) .GT. 1.2 .OR. RSBFRC(KRS) .LT. 0.6) GO TO 117      SHM11560
      RSL = NDRS(KRS)                                                   SHM11570
      BFRC = BFRC + RSBFRC(KRS)*RSL                                     SHM11580
      ABFSL = ABFSL + RSL                                               SHM11590
      IF(LBFO(KRS))  GO TO 118                                          SHM11600
      IF(RSL .GE. 20.0) RSL = 20.0                                      SHM11610
      IFRC = IFRC + RSIFRC(KRS)*RSL                                     SHM11620
      AIFSL = AIFSL + RSL                                               SHM11630
      GO TO 118                                                         SHM11640
17    WRITE(6,3) KRS                                                    SHM11650
3     FORMAT(10X,'SEQUENCE',I3,1X,'OMITTED IN AVERAGING')               SHM11660
18    CONTINUE                                                          SHM11670
      WRITE(6,4) ABFSL,AIFSL                                            SHM11680
4     FORMAT(10X,'BASE FLOW DAYS =',F5.0,2X,'INTERFLOW DAYS =',F5.0)    SHM11690
      BFRC = BFRC/ABFSL                                                 SHM11700
      IFRC =IFRC/AIFSL                                                  SHM11710
      IF(BFRC .GT. 0.99) BFRC = 0.99                                    SHM11720
      IF(BFRC .LT. 0.70) BFRC = 0.70                                    SHM11730
      KSQ = 0                                                           SHM11740
      DO 119 KRS = 1,NTRS                                               SHM11750
      IF(LBFO(KRS)) GO TO 119                                           SHM11760
      CALL SETRBF(RSTF,NDRS,KRS,BFRC,IFRC,CRSBIF,CRSBBF)                SHM11770
      IF(CRSBIF .GT. 95000.0 .OR. CRSBBF .LT. 0.0) GO TO 119            SHM11780
      IF(CRSBIF .LT. 0.0) CRSBIF = 0.0                                  SHM11790
      KSQ = KSQ + 1                                                     SHM11800
      RSBD (KSQ) = RSBD(KRS)                                            SHM11810
      RSBIF(KSQ) = CRSBIF                                               SHM11820
      RSBBF(KSQ) =CRSBBF                                                SHM11830
119   CONTINUE                                                          SHM11840
      NRS = KSQ                                                         SHM11850
      DO 120 KSQ = 1,NRS                                                SHM11860
      DAY = RSBD(KSQ)                                                   SHM11870
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      CALL DAYNXT(DAY,DPY)
 120  RSBD(KSQ) = DAY
      DO 121 KSQ = 1,NRS
      CRSBTF = RSBIF(KSQ) + RSBBF(KSQ)
 121  WRITE(6,5) KSQ,RSBD(KSQ),RSBIF(KSQ),RSBBF(KSQ),CRSBTF
  5   FORMAT(/10X,'REVISED FLOW SEQUENCE',I3,1X,'BEGINS ON DAY',I4,
     1  1X,'AT INTERFLOW =',F7.2,1X,'CFS,  BASE FLOW =',F7.2,1X,'CFS,
     2  TOTAL =',F7.2,1X,'CFS')
      RETURN
      END
      SUBROUTINE SETBIV(BIVF,NRS,IFRC,RSBIF,SIFRS,FNCTRH)
   SETS BEST VALUE OF BASIC INTERFLOW VOLUME FACTOR
      DIMENSION RSBIF(20),SIFRS(3,20)
      REAL  IFRC
      ARSTR = 0.0
      DO 101 KRS = 1,NRS
      RIF = RSBIF(KRS)/IFRC
      DO 100 KDY = 1,3
      RIF = RIF*IFRC
      SIF = SIFRS(KDY,KRS)/IFRC**(FNCTRH/48.0)
      RSTR = 0.0
      IF(RIF .GT. 0.0) RSTR = SIF/RIF
      IF(RSTR .GT. 3.0 .OR. (SIF .GT. 0.0 .AND. RIF .EQ. 0.0))RSTR=3.0
      ARSTR = ARSTR +RSTR
      WRITE(6,1) KRS,KDY,SIF,RIF
  1   FORMAT(10X,'KRS=',I3,2X,'KDY=',I2,2X,'SIF=',F7.1,5X,'RIF=',
     1  F7.1)
 100  CONTINUE
 101  CONTINUE
      TIRD = NRS*3
      PBIVF = BIVF
      BIVF = 0.40
      IF(ARSTR .GT. 0.0) BIVF = ((PBIVF-0.40)*TIRD)/ARSTR + 0.40
      WRITE(6,2) PBIVF,BIVF
  2   FORMAT(5X,'BIVF CHANGED FROM',F6.2,2X,'TO',F6.2//)
      RETURN
      END
      SUBROUTINE SETBMI(BMIR,NRS,BFRC,RSBBF,SBFRS,FNCTRH,IFT)
C   SETS BEST VALUE OF BASIC MAXIXMUM INFILTRATION RATE WITHIN WATERSHED
      DIMENSION RSBBF(20),SBFRS(3,20)
      ARSTR = 0.0
       DO 101 KRS = IFT,NRS
      RBF = RSBBF(KRS)/BFRC
      DO 100 KDY = 1,3
      RBF = RBF*BFRC
      SBF = SBFRS(KDY,KRS)/BFRC**(FNCTRH/48.0)
      RSTR = SBF/RBF
      IF(RSTR .GT. 3.0) RSTR =3.0
      ARSTR = ARSTR + RSTR
      WRITE(6,1) KRS,KDY,SBF,RBF
  1   FORMAT(10X,'KRS=',I3,2X,'KDY=',I2,2X,'SBF=',F7.1,5X,'RBF=',
     1  F7.1)
 100  CONTINUE
 101  CONTINUE
```

```
      TBRD =(NRS + 1-IFT)*3
      ARSTR = ARSTR/TBRD
      ARSTR = ARSTR**1.3
      PBMIR =BMIR
      BMIR = PBMIR/ARSTR
      WRITE(6,2) PBMIR,BMIR
  2   FORMAT(5X,'BMIR CHANGED FROM',F6.2,2X,'TO',F6.2//)
      RETURN
      END
      SUBROUTINE SETFDI(MFDP,TMSTF,TMRTF,SSQM)
   SETS VALUES OF FLOW DEVIATION INDICES
      DIMENSION MFDP(12),TMRTF(12),TMSTF(12)
      REAL  MFDP
      DO 101 MONTH = 1,12
      IF(MONTH .LE. 2) SSQM = 0.0
      SMFX = TMSTF(MONTH) + 20.0
      RMFX = TMRTF(MONTH) + 20.0
      MFDP(MONTH) = SMFX/RMFX - 1.0
      IF(MFDP(MONTH) .GT. 8.0) MFDP(MONTH) = 8.0
      IF(MFDP(MONTH) .LT. 0.0) MFDP(MONTH) = 1.0 -RMFX/SMFX
      IF(MFDP(MONTH) .LT.(-8.0))MFDP(MONTH) = -8.0
100   SSQM = SSQM + MFDP(MONTH)*MFDP(MONTH)
101   CONTINUE
      WRITE(6,1) (MFDP(MONTH), MONTH=1,12), SSQM
  1   FORMAT(//2X,'MONTHLY DEVIATIONS',/16X,12(F7.3,1X),'SSQM =',F7.3)
      RETURN
      END
      SUBROUTINE SETFVP(LZC,SUZC,ETLF,BUZC,SIAC,TMSTF,TMRTF,TMPREC,
     1 TMPET,EMLZS,SSQM,LRC,XMPFT,FTX,NOFM,LBUZC,LETLF,LLZC,APREC,APET)
C  SETS BEST VALUES OF FLOW VOLUME PARAMETERS
      DIMENSION EMLZS(12),MFDP(12),MXA(12),TMPET(12),TMPREC(12),
     1  TMRTF(12),TMSTF(12),XMPFT(12)
      LOGICAL LBUZC,LETLF,LLZC,LRC
      REAL LZC,MFDP
      CALL SETFDI(MFDP,TMSTF,TMRTF,SSQM)
      IF((MFDP(2)+MFDP(3)) .GT. 2.0 .AND. FTX .LT. 1.05) FTX= 0.9
      IF((MFDP(2)+MFDP(3)) .LT.(-2.0).AND. FTX .GT. 0.95) FTX=1.1
C  ADJUSTMENT OF LZC BASED ON MONTHS WHERE OVER HALF OF TOTAL
C    SYNTHESIZED RUNOFF IS OVERLAND FLOW,MINIMUM OF TWO MONTHS
C    WITH GREATEST RUNOFF USEC
      PLZC = LZC
      FNOFM = NOFM
       IF(NOFM .GT. 2) GO TO 103
      M1R = 2
      M2R = 1
      IF(TMRTF(2).GT. TMRTF(1)) GO TO 100
      M1R = 1
      M2R = 2
100   DO 102 MONTH = 3,12
      IF(TMRTF(MONTH) .LT. TMRTF(M2R)) GO TO 102
      IF(TMRTF(MONTH) .GT. TMRTF(M1R)) GO TO 101
      M2R = MONTH
      GO TO 102
101   M2R = M1R
```

```
      PRM2 = TMPREC(MONTH)
112   CONTINUE
      FSUZC = MFDP(M1SP) + MFDP(M2SP)
      IF(ABS(XMPFT(12) - 1.0) .GT. 0.2) GO TO 113
      FSUZC = FSUZC +MFDP(12)
      M12 = 12
 113  IF(ABS(XMPFT(11) - 1.0) .GT. 0.2) GO TO 114
      FSUZC = FSUZC + MFDP(11)
      M11 = 11
114   IF(FSUZC  .GT. 1.0) FSUZC = 1.0
      IF(FSUZC .LT.(-1.0)) FSUZC = -1.0
      IF(FSUZC .GT. 0.0) SUZC = (FSUZC + 1.0)*SUZC
      IF(FSUZC .LE. 0.0) SUZC = SUZC/(1.0-FSUZC)
      WRITE(6,3) SUZC,M1SP,M2SP,M11,M12
 3    FORMAT(4X,'SUZC WAS CHANGED TO',F6.2,' BASED ON MONTHS',4I3)
      IF(SUZC .LT. 0.3 .AND. LRC) SUZC = 0.3
      IF(SUZC .GT. 3.0 .AND.LRC) SUZC = 3.0
   ADJUSTMENT OF ETLF BASED ON SUMMER MONTHS OF RAINFALL EXCEEDING TWO
     INCHES OR NEED TO PREVENT MOISTURE BUILDUP
      IF(EMLZS(12) .LT. PLZC .OR. EMLZS(11) .LT. PLZC .OR. APREC .GT.
     1  1.5*APET) GO TO 115
      FETLF = 1.0
      MXA(1) = 13
      KWSM = 1
      GO TO 120
 115  SWSMD = 0.0
      KWSM = 0
      DO 116 MONTH = 1,12
      IF((MONTH .GT. MBWS .OR . MONTH .GT. 2) .AND. (MONTH .LT. MBDS
     1  .AND. MONTH .LT. 9)) GO TO 116
      IF(TMPREC(MONTH) .LT. 2.0) GO TO 116
      SWSMD = SWSMD + MFDP(MONTH)
      KWSM = KWSM + 1
      MXA(KWSM) = MONTH
 116  CONTINUE
      IF(KWSM .GE. 1) GO TO 117
      MXA(1) = M1R
      KWSM = 1
      FETLF = 5.0*MFDP(M1R)
      GO TO 120
117   WSM = KWSM
      IF( .NOT. LETLF .OR. KWSM .EQ. 1) GO TO 119
      EMFDP = 0.0
      DO 118 MONTH = 1,KWSM
      KM1 = MXA(MONTH)
      IF(MFDP(KM1) .LT. EMFDP) GO TO 118
      EMFDP = MFDP(KM1)
      KM2 = MONTH
118   CONTINUE
      MXA(KM2) = 0
      SWSMD = SWSMD -EMFDP
      WSM = WSM -1.0
119   FETLF = 1.2*SWSMD/WSM
120   IF(FETLF .GT. 1.0) FETLF =1.0
```

```
      IF(FETLF .LT.(-1.0))FETLF = -1.0
      IF(FETLF  .GT. 0.0) ETLF = (FETLF + 1.0)*ETLF
      IF(FETLF .LT. 0.0) ETLF =ETLF/(1.0 -FETLF)
      WRITE(6,4) ETLF,(MXA(KWD), KWD = 1,KWSM)
    4 FORMAT(4X,'ETLF WAS CHANGED TO',F6.2,' BASED ON MONTHS',12I3)
      IF(ETLF .LT. 0.05.AND. LRC) ETLF = 0.05
      IF(ETLF .GT. 0.6 .AND. LRC) ETLF = 0.6
  ADJUSTMENT OF BUZC BASED ON SEPTEMBER, NOVEMBER, AND DECEMBER
      KM1 = 12
      KM2 = 2
      KM3 = 3
      FBUZC = 0.4*(MFDP(12) +MFDP(2) + MFDP(3))
      IF( .NOT. LBUZC) GO TO 121
      FBUZC = 0.4*(MFDP(9) + MFDP(10) + MFDP(11))
      KM1 = 9
      KM2 = 10
      KM3 = 11
  121 IF(FBUZC .GT. 1.0) FBUZC = 1.0
      IF(FBUZC .LT.(-1.0))FBUZC = -1.0
      IF(FBUZC .GT. 0.0) BUZC = (FBUZC + 1.0)*BUZC
      IF(FBUZC .LE. 0.0) BUZC=BUZC/(1.0-FBUZC)
      WRITE(6,5) BUZC,KM1,KM2,KM3
    5 FORMAT(4X,'BUZC WAS CHANGED TO',F6.2,' BASED ON MONTHS',3I3)
      IF(BUZC .LT. 0.2 .AND. LRC) BUZC = 0.2
      IF(BUZC .GT. 4.0 .AND. LRC) BUZC = 4.0
  ADJUSTMENT OF SIAC BASED ON THREE FIRST MOISTURE EXCESS AND THREE
     FIRST MOISTURE DEFICIENT MONTHS
      KM1 = MBDS
      KM2 = MBDS + 1
      KM3 = MBDS -1
      KM4 = 0
      KM5 = 0
      KM6 = 0
      WFDX = 0.0
      IF(SIAC .GT. 1.0) GO TO 122
      WFDX = (MFDP(MBWS) + MFDP(MBWS +1) + MFDP(MBWS+2))/3.0
      IF(SIAC .GT. 0.6) WFDX = WFDX*(1.0- SIAC)/0.4
      KM4 = MBWS
      KM5 = MBWS + 1
      KM6 = MBWS +2
  122 SFDX = (MFDP(MBDS) + MFDP(MBDS+1) + MFDP(MBDS-1))/3.0
      FSIAC = 1.5*(SFDX-WFDX)
      IF(FSIAC .GT. 1.0) FSIAC = 1.0
      IF(FSIAC .LE.(-1.0))FSIAC = -1.0
      IF(SIAC .LT. 0.02) SIAC = 0.02
      IF(FSIAC .GT. 0.0) SIAC = (FSIAC + 1.0)*SIAC
      IF(FSIAC .LE. 0.0) SIAC = SIAC/(1.0-FSIAC)
      WRITE(6,6) SIAC,KM4,KM5,KM6,KM3,KM1,KM2
    6 FORMAT(4X,'SIAC WAS CHANGED TO',F6.2,' BASED ON MONTHS',6I3)
      IF(SIAC .LT. 0.02 .AND. LRC) SIAC = 0.00
      IF(SIAC .GT. 4.0 .AND. LRC) SIAC = 4.0
      RETURN
      END
      SUBROUTINE SETHRP(CTRI,BTRI,WCFS,CONOP2,HBF,LSHA,SSR,NHPT,KPSH,
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     1  IBTPR,SRX,CSRX,FSRX,CHCAP,NRHP,RHPF,NCTRI,NBTRI)
C SETS BEST VALUES OF HYDROGRAPH ROUTING PARAMETERS
      DIMENSION BTRI(99),CTRI(99),HBF(5),HSRX(5),KPSH(5),LSHA(5),
     1  HNTRI(5),RHPF(5),SRR(5,170),SSR(5,170),TSRX(7)
      LOGICAL LSHA
      INTEGER  CONOP2,HNTRI,SNTRI
      REAL NHPT
      MHTP = 1
      IF(CONOP2 .EQ. 0) MHTP = 4
      MXTRI = 2*NBTRI
      MNTRI = NBTRI/2
      TSRX(1) = 0.995
      TSRX(2) = 0.99
      TSRX(3) = 0.985
      TSRX(4)  = 0.98
      TSRX(5) = 0.96
      TSRX(6) = 0.93
      TSRX(7) = 0.90
      LNIBRS = 0
      DO 112 KHYD = 1,NRHP
      IF( .NOT. LSHA(KHYD)) GO TO 112
      KPCH = KPSH(KHYD)
      NCTRI = MNTRI
      CALL FIXTRI(CTRI,BTRI,NBTRI,NCTRI)
      KH1 = 1
      KH2 = 1
      KH3 = 1
      SDRSP = 80.0*CHCAP
      SNTRI = MXTRI
  100 SRX = TSRX(KH1)
      IF(KH2 .EQ. 2) LNIBRS =NIBRS
      WRITE(6,1) NCTRI,SRX
    1 FORMAT(//15X,'TRIAL VALUE OF NCTRI =',I3,',  SRX =',F6.3)
      CALL TIMERT (SSR,SRR,CTRI,NCTRI,KHYD,KPCH)
      CSRX = SRX
      FSRX = SRX
      CALL STORRT(SRR,CSRX,FSRX,CHCAP,CONOP2,IBTPS,SHPF,KHYD,HBF(KHYD),
     1  NHPT,KPCH,IBTPR)
      LNTRI = NCTRI
      NIRTS = IBTPS- IBTPR*MHTP
      NIBRS = IABS(NIRTS)
      DRSP = ABS(SHPF - RHPF(KHYD))
      IF(NIRTS .EQ. 0 .OR. (KH2 .EQ. 2 .AND. NIBRS .GE. LNIBRS) .OR.
     1  RHPF(KHYD) .GT. 1.2*SHPF) GO TO 103
      IF(NIRTS .GE. 1) GO TO 109
  101 NCTRI = NCTRI -NIRTS
      IF(NCTRI .LT. MNTRI) NCTRI = MNTRI
      IF(NCTRI .GT. MXTRI) GO TO 106
  102 CALL FIXTRI(CTRI,BTRI,NBTRI,NCTRI)
      KH2 = 2
      GO TO 100
  103 IF(DRSP .GT. SDRSP) GO TO 108
      SNTRI = LNTRI
      SDRSP = DRSP
```

```
      KH3 = 2
104   KH1 = KH1 + 1
      IF(KH1 .EQ. 8) GO TO 105
      KH2 = 1
      GO TO 100
105   HNTRI(KHYD) = LNTRI
      HSRX(KHYD) = SRX
      GO TO 111
 106  IF(KH1 .GE. 2 .AND. KH3 .EQ.  2 .AND. DRSP .GE. SDRSP) GO TO 108
      NCTRI = MXTRI
      CALL FIXTRI(CTRI,BTRI,NBTRI,NCTRI)
      IF(KH2 .EQ. 2 .AND. KH1 .EQ. 1 .AND. SHPF .GT. RHPF(KHYD)) GO
     1  TO 107
      IF( KH2 .EQ. 2 .OR. KH1 .GE. 2) GO TO 109
      GO TO 102
107   HNTRI(KHYD) = MXTRI
      HSRX(KHYD) = 0.995
      GO TO 111
108   HSRX(KHYD) = TSRX(KH1-1)
      HNTRI(KHYD) = SNTRI
      GO TO 111
109   IF(NCTRI .GT. MNTRI .AND. NCTRI .LT. MXTRI) GO TO 101
      IF(DRSP .GT. SDRSP) GO TO 110
      SDRSP = DRSP
      SNTRI = LNTRI
      GO TO 104
110   HNTRI(KHYD) = NCTRI
      HSRX(KHYD) = 0.995
      IF(KH1 .GE. 2) HSRX(KHYD) = TSRX(KH1 - 1)
111   IF(HSRX(KHYD) .LT. 0.91 .AND. SHPF .LT. 0.5*RHPF(KHYD)) LSHA(KHYD)
     1  = .FALSE.
      IF(.NOT. LSHA(KHYD)) GO TO 112
      WRITE(6,2) KHYD,HNTRI(KHYD),HSRX(KHYD)
 2    FORMAT(10X,'FOR STORM ',I2,' NCTRI =',I3,' SRX =',F6.3)
112   CONTINUE
      KPA = 1
113   ARHPF = 0.0
      APPKP = 0.0
      DO 114 KHYD = 1,NRHP
      IF( .NOT. LSHA(KHYD)) GO TO 114
      CHPV = HNTRI(KHYD)
      IF(KPA .EQ. 2) CHPV = HSRX(KHYD)
      APPKP = APPKP + CHPV*RHPF(KHYD)
      ARHPF = ARHPF + RHPF(KHYD)
114   CONTINUE
      WAPV = APPKP/ARHPF
      IF(KPA .EQ. 2) GO TO 115
      NCTRI = WAPV + 0.5
      WRITE(6,3) NCTRI
 3    FORMAT(//10X,'OPTIMUM NCTRI =',I3)
      IF(NCTRI .EQ. 0) RETURN
      CALL FIXTRI(CTRI,BTRI,NBTRI,NCTRI)
      WRITE(6,4) (CTRI(KTRI), KTRI = 1,NCTRI)
 4    FORMAT(18X,'CTRI ARE'/9(16X,11F8.4/))
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      WRITE(6,5)
 5    FORMAT(18X,'WARNING- THE USER MAY HAVE TO ADJUST THESE VALUES TO
     1MAKE THEM ADD TO ONE TO COMPENSATE FOR ROUNDING.')
      KPA = 2
      GO TO 113
115   SRX = WAPV
      CSRX = SRX
      FSRX = SRX
      CALL SETSRP(CONOP2,NRHP,LSHA,RHPF,HSRX,CHCAP,SSR,SRR,CTRI,CSRX,
     1  FSRX,KHYD,IBTPS,SHPF,NCTRI,HBF,NHPT,KPSH,IBTPR)
      SRX = CSRX
      RETURN
      END
      SUBROUTINE SETRBF(RSTF,NDRS,KRS,BFRC,IFRC,CRSBIF,CRSBBF)
  SETS VALUES OF INTERFLOW AND BASE FLOW AT RECESSION BEGINNING
      DIMENSION RSTF(50,20),NDRS(20)
      REAL*8  RA1,RA2,RA3,RA4,RA5,RA6
      REAL IFRC
      RA1 = 0.0
      RA2 = 0.0
      RA3 = 0.0
      RA4 = 0.0
      RA5 = 0.0
      MNDRS = 12
      IF(NDRS(KRS) .LT. 12) MNDRS = NDRS(KRS)
      IF(IFRC .GE. 0.3) GO TO 101
      CRSBIF = 0.0
      DO 100 KSD = 1,MNDRS
      RA1 = RA1 + BFRC**(2*KSD)
100   RA4 = RA4 + RSTF(KSD,KRS)*(BFRC**KSD)
      CRSOBF= RA4/RA1
      CRSBBF = CRSOBF*BFRC
      RETURN
 101  CRSBIF = 100000.0
      DO 102 KSD = 1,MNDRS
      RA1 = RA1 + BFRC**(2*KSD)
      RA2 = RA2 + IFRC**(2*KSD)
      RA3 = RA3 + (BFRC*IFRC)**KSD
      RA4 = RA4 + RSTF(KSD,KRS)*(BFRC**KSD)
      RA5 = RA5 + RSTF(KSD,KRS)*(IFRC**KSD)
 102  CONTINUE
      RA6 = RA1*RA2 -RA3**2
      IF(RA6 .EQ. 0.0) RETURN
      CRSOIF = -(RA3/RA6)*RA4 +(RA1/RA6)*RA5
      CRSBIF = CRSOIF*IFRC
      CRSOBF = (RA2/RA6)*RA4 -(RA3/RA6)*RA5
      CRSBBF = CRSOBF*BFRC
      RETURN
      END
      SUBROUTINE SETSRP(CONOP2,NRHP,LSHA,RHPF,HSRX,CHCAP,SSR,SRR,CTRI,
     1  CSRX,FSRX,KHYD,IBTPS,SHPF,NCTRI,HBF,NHPT,KPSH,IBTPR)
C  SETS BEST VALUES OF STORAGE ROUTING PARAMETERS
      DIMENSION CTRI(99),HBF(5),HSRX(5),KPSH(5),LSHA(5),RHPF(5),
     1  SRR(5,170),SSR(5,170)
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      LOGICAL  LSHA                                                     SHM16200
      INTEGER CONOP2                                                    SHM16210
      REAL NHPT                                                         SHM16220
      KLCCA = 1                                                         SHM16230
      SRX = CSRX                                                        SHM16240
      EPS = 0.000001                                                    SHM16250
      NORHP = NRHP                                                      SHM16260
      DO 100 KHYD = 1,NORHP                                             SHM16270
      IF( .NOT. LSHA(KHYD)) NRHP = NRHP-1                               SHM16280
100   CONTINUE                                                          SHM16290
      IF(NRHP .LE. 2) GO TO 103                                         SHM16300
   FIND REGRESSION LINE FOR DETERMINING CSRX,WHEN NRHP EXCEEDS 3        SHM16310
      RA1 = 0.0                                                         SHM16320
      RA2 =0.0                                                          SHM16330
      RA3 = 0.0                                                         SHM16340
      RA4 = 0.0                                                         SHM16350
      FNRHP = NRHP                                                      SHM16360
      DO 101 KHYD = 1,NORHP                                             SHM16370
      IF(.NOT. LSHA(KHYD)) GO TO 101                                    SHM16380
      RA1 = RA1 + RHPF(KHYD)                                            SHM16390
      RA2 = RA2 + HSRX(KHYD)                                            SHM16400
      RA3 = RA3 + RHPF(KHYD)*HSRX(KHYD)                                 SHM16410
      RA4 = RA4 + RHPF(KHYD)**2                                         SHM16420
101   CONTINUE                                                          SHM16430
      AVRHPF = RA1/FNRHP                                                SHM16440
      ASRX = RA2/FNRHP                                                  SHM16450
      RSLP =(RA3 -RA1*ASRX)/(RA4-RA1**2/FNRHP)                          SHM16460
      IF(RSLP .LE. EPS) GO TO 106                                       SHM16470
      RINT = ASRS -RSLP*AVRHPF                                          SHM16480
102   CSRX =  RINT + RSLP*(0.5*CHCAP)                                   SHM16490
      IF(CSRX .GE. 0.99) RETURN                                         SHM16500
      IF(CSRX .LE. 0.8) CSRX = 0.8                                      SHM16510
      GO TO 107                                                         SHM16520
 103  K1AH = 0                                                          SHM16530
      DO 104 KHYD = 1,NORHP                                             SHM16540
      IF(.NOT. LSHA(KHYD)) GO TO 104                                    SHM16550
      IF(K1AH .EQ. 0) K1AH = KHYD                                       SHM16560
      IF(K1AH .GT. 0) K2AH= KHYD                                        SHM16570
 104   CONTINUE                                                         SHM16580
      IF(NRHP .EQ. 1) GO TO 105                                         SHM16590
C  FIT THE STRAGHT LINE WHEN NRHP = 2                                   SHM16600
      RSLP = (HSRX(K1AH) -HSRX(K2AH))/(RHPF(K1AH)- RHPF(K2AH))          SHM16610
      IF(RSLP .LE. EPS) GO TO 106                                       SHM16620
      RINT = HSRX(K1AH) -RSLP*RHPF(K1AH)                                SHM16630
      GO TO 102                                                         SHM16640
 105  CONTINUE                                                          SHM16650
      CSRX = HSRX(K1AH)                                                 SHM16660
      FSRX = CSRX                                                       SHM16670
      GO TO 115                                                         SHM16680
 106  CONTINUE                                                          SHM16690
      CSRX = SRX                                                        SHM16700
      FSRX = CSRX                                                       SHM16710
      WRITE(6,1)                                                        SHM16720
 1    FORMAT(//10X,'REGRESSION LINE HAS NEGATIVE SLOPE')                SHM16730
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      GO TO 115
107   CONTINUE
      BISRX = 0.2*(0.99 - CSRX)
      SISRX = 0.04*(0.99-CSRX)
      TFSRX = CSRX
      KISRX = 0
108   KISRX = KISRX + 1
      FSRX = TFSRX
      WRITE(6,2) KISRX,CSRX,FSRX,CHCAP
 2    FORMAT(//15X,'TRIAL',I3,',    CSRX =',F8.5,',    FSRX =',F8.5,
     1  ',    CHCAP =',F10.0)
      SQPKD = 0.0
      ADRSP = 0.0
      DO 109 KHYD = 1,NORHP
      IF(.NOT. LSHA(KHYD)) GO TO 109
      KPCH = KPSH(KHYD)
      CALL TIMERT(SSR,SRR,CTRI,NCTRI,KHYD,KPCH)
      CALL STORRT(SRR,CSRX,FSRX,CHCAP,CONOP2,IBTPS,SHPF,KHYD,HBF(KHYD),
     1  NHPT,KPCH,IBTPR)
      DRSP = SHPF - RHPF(KHYD)
      SQPKD = SQPKD + DRSP**2
      ADRSP = ADRSP +DRSP
109   CONTINUE
      WRITE(6,3) SQPKD
 3    FORMAT(/25X,'SQPKD =',F14.0)
      IF(KISRX .NE. 1) GO TO 110
      TFSRX = CSRX + BISRX
      SSQPKD = SQPKD
      BFSRX = FSRX
      GO TO 108
 110  IF(SQPKD .GT. SSQPKD) GO TO 113
      IF(KISRX .EQ. 6 .AND. ADRSP .GT. 0.0) GO TO 111
      SSQPKD = SQPKD
      BFSRX = FSRX
      IF(KISRX .GE. 11) GO TO 114
      IF(KISRX .LE. 5) TFSRX = TFSRX +BISRX
      IF(KISRY .GE. 6) TFSRX =TFSRX -SISRX
      GO TO 108
111   KLCCA = KLCCA + 1
      IF(KLCCA .GE. 5) GO TO 112
      CHCAP = 0.8*CHCAP
      CSRX = RINT + RSLP*(0.5*CHCAP)
      GO TO 107
112   CSRX = 0.990
      FSRX = 0.990
      GO TO 115
113   IF(KISRX .GT. 6) GO TO 114
      KISRX = 6
      SSQPKD = SQPKD
      BFSRX = FSRX
      TFSRX = TFSRX -SISRX
      GO TO 108
114   FSRX = BFSRX
      WRITE(6,4) CSRX,FSRX,SSQPKD
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 4    FORMAT(//10X,'CSRX =',F7.4,10X,'FSRX =',F7.4,10X,'SQPKD =',F15.2)  SHM17280
      RETURN                                                              SHM17290
115   WRITE(6,5) CSRX,FSRX                                                SHM17300
 5    FORMAT(//10X,'CSRX =',F7.4,10X,'FSRX =',F7.4)                       SHM17310
      RETURN                                                              SHM17320
      END                                                                 SHM17330
      SUBROUTINE SET1RC(RSTF,KRS,NDRSC,BFRC)                              SHM17340
   SETS BEST VALUE FOR ONE RECESSION CONSTANT                             SHM17350
      DIMENSION RSTF(50,20)                                               SHM17360
      RA1 = 0.0                                                           SHM17370
      RA2 = 0.0                                                           SHM17380
      NDRSC1 = NDRSC -1                                                   SHM17390
      DO 100 KSD = 1,NDRSC1                                               SHM17400
      RA1 = RA1  + RSTF(KSD,KRS)**2                                       SHM17410
100   RA2 = RA2 + RSTF(KSD,KRS)*RSTF(KSD+1,KRS)                           SHM17420
      BFRC = RA2/RA1                                                      SHM17430
      WRITE(6,1) KRS,BFRC                                                 SHM17440
 1    FORMAT(15X,'KRS =',I3,5X,'BFRC =',F8.4)                             SHM17450
      RETURN                                                              SHM17460
      END                                                                 SHM17470
      SUBROUTINE SET2RC(RSTF,KRS,NDRSC,IFRC,BFRC,LBFO)                    SHM17480
   SETS BEST VALUES FOR TWO RECESSION CONSTANTS                           SHM17490
      DIMENSION RSTF(50,20)                                               SHM17500
      LOGICAL LBFO                                                        SHM17510
      REAL IFRC                                                           SHM17520
      REAL*8  RA1,RA2,RA3,RA4,RA5,CRSTF(50),RA6,DBFRC,DIFRC,RA,RB,RD      SHM17530
      DO 100 KSD = 1,NDRSC                                                SHM17540
 100  CRSTF(KSD) = RSTF(KSD,KRS)                                          SHM17550
      NDRSC2 = NDRSC -2                                                   SHM17560
      RA1 = 0.0                                                           SHM17570
      RA2 = 0.0                                                           SHM17580
      RA3  = 0.0                                                          SHM17590
      DO 101 KSD = 1,NDRSC2                                               SHM17600
      RA1 = RA1 + CRSTF(KSD)**2                                           SHM17610
      RA2 = RA2 +CRSTF(KSD)*CRSTF(KSD+1)                                  SHM17620
 101  RA3 = RA3+CRSTF(KSD)*CRSTF(KSD+2)                                   SHM17630
      RA4 = RA1 +CRSTF(NDRSC-1)**2 -CRSTF(1)**2                           SHM17640
      RA5 = RA2 + CRSTF(NDRSC-1)*CRSTF(NDRSC) - CRSTF(1)*CRSTF(2)         SHM17650
      RA6 = RA4*RA1 -RA2**2                                               SHM17660
      IF(RA6 .EQ. 0.0) GO TO 102                                          SHM17670
      RA5 = RA5/RA6                                                       SHM17680
      RA3 = RA3/RA6                                                       SHM17690
      RA = RA1*RA5 - RA2*RA3                                              SHM17700
      RB = RA4*RA3 - RA2*RA5                                              SHM17710
      RD = RA**2 + 4.0*RB                                                 SHM17720
      IF(RD .LT. 0.0) GO TO 102                                           SHM17730
      DBFRC = (RA +RD **0.5)/2.0                                          SHM17740
      DIFRC = RA -DBFRC                                                   SHM17750
      BFRC = DBFRC                                                        SHM17760
      IFRC = DIFRC                                                        SHM17770
      WRITE(6,1) KRS,BFRC,IFRC                                            SHM17780
 1    FORMAT(15X,'KRS =',I3,5X,'BFRC =',F8.4,5X,'IFRC =',F8.4)            SHM17790
      GO TO 103                                                           SHM17800
102   LBFO = .TRUE.                                                       SHM17810
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      WRITE(6,2) KRS
  2   FORMAT(/15X,'IMAGINARY VALUES ENCOUNTERED IN SET2RC, SEQUENCE =',
     1  I3)
103   RETURN
      END
      SUBROUTINE STORRT(SRR,CSRX,FSRX,CHCAP,CONOP2,IBTPS,SHPF,KHYD,
     1  CHBF,NHPT,KPCH,IBTPR)
C PERFORMS CHANNEL STORAGE ROUTING
      DIMENSION ASRR(5,21),SRR(5,170)
      INTEGER CONOP2,PRD
      REAL  NHPT
      WRITE(6,1) CHBF
  1   FORMAT(/25X,'BASE FLOW =',F7.1,' CFS')
      TFCFS = CHBF
      INHPT = NHPT
      MHTP = 1
      IF(CONOP2 .EQ. 0) MHTP = 4
      INHPT = MHTP*INHPT
      SHPF = 0.0
      RHF0 = 0.9*SRR(KHYD,1)
      KAFH = 0
      DO 102 KHPT = 1,KPCH
      PRD = 0
100   PRD = PRD + 1
      TRHF = SRR(KHYD,KHPT)
      IF(TFCFS .LE. 0.5*CHCAP) SRX = CSRX
      IF((TFCFS .GT. 0.5*CHCAP) .AND. (TFCFS .LT. 2.0*CHCAP)) SRX =
     1  CSRX + (FSRX -CSRX)*((TFCFS -0.5*CHCAP)/(1.5*CHCAP))**3
      IF(TFCFS .GE. 2.0*CHCAP) SRX = FSRX
      RHF1 = TRHF- SRX*(TRHF -RHF0)
      RHF0 = RHF1
      TFCFS = RHF1 + CHBF
      IF(TFCFS .LT. SHPF) GO TO 101
      SHPF = TFCFS
      IBTPS = KHPT
101   IF(PRD .LE. 3 .AND. CONOP2 .EQ. 1) GO TO 100
      KAHP = KHPT - IBTPR*MHTP + 5*INHPT
      IF(KAHP .LT. 0) GO TO 102
      IF(MOD(KAHP,INHPT) .NE. 0) GO TO 102
      KAFH = KAFH + 1
      ASRR(KHYD,KAFH) = TFCFS
102   CONTINUE
      IF(KAFH .EQ. 21) GO TO 104
      KAFH = KAFH + 1
      DO 103 KIA = KAFH,21
103   ASRR(KHYD,KIA) = 0.0
104   WRITE(6,2) KHYD,NHPT,(ASRR(KHYD,KWD), KWD = 1,21)
  2   FORMAT(/25X,'SYNTHESIZED HYDROGRAPH',I3,' INTERVAL =',F5.2,
     1  'HOURS'/3(22X,7F10.1/))
      WRITE(6,3) SHPF
  3   FORMAT(25X,'FLOOD PEAK =',F10.1,' CFS')
      RETURN
      END
      SUBROUTINE STRHRS(RHPD,RHPH,IDYB,IDYE,IHRB,IHRE,NHPT,MXTRH,DPY,
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   1  NRHP,IBTPR)
  SETS BEGINNING AND END TIMES OF RUNOFF ENTERING RECORED HYDROGRAPHS
      DIMENSION RHPD(5),RHPH(5),IDYB(5),IDYE(5),IHRB(5),IHRE(5)
      INTEGER DAY,DPY,RHPD,RHPH
      REAL NHPT
  ESTIMATE HOURS EACH WAY FROM PEAK
      INHPT = NHPT
      IBTPR = 5*INHPT + MXTRH
      IPTE = 15*INHPT
  DETERMINE TIME OF BEGINNING AND ENDING FOR EACH STORM
      DO 106 KRHP = 1,NRHP
      KHBCK = IBTPR - RHPH(KRHP)
      IF(KHBCK . LT. 0) GO TO 101
      KDBCK = KHBCK/24 + 1
      IHRB(KRHP) = 24*KDBCK-KHBCK
      DAY = RHPD(KRHP)
100   DAY = DAY -1
      IF(DAY.EQ. 59 .AND. DPY .EQ. 366) DAY = 366
      IF(DAY .EQ. 365) DAY = 59
      IF(DAY .EQ. 0) DAY = 365
      KDBCK = KDBCK - 1
      IF(KDBCK .GT. 0) GO TO 100
      IDYB(KRHP) = DAY
      GO TO 102
 101  IDYB(KRHP) = RHPD(KRHP)
      IHRB(KRHP) = RHPH(KRHP)- IBTPR
102   KHFOR = IPTE + RHPH(KRHP)
      IF(KHFOR .LE. 24) GO TO 105
      KDFOR = KHFOR/24
      IHRE(KRHP) = KHFOR -24*KDFOR
      IF(IHRE(KRHP) .NE. 0)GO TO 103
      KDFOR = KDFOR - 1
103   DAY = RHPD(KRHP)
104   CALL DAYNXT(DAY,DPY)
      KDFOR = KDFOR - 1
      IF(KDFOR .GT. 0) GO TO 104
      IDYE(KRHP) = DAY
      GO TO 106
105   IDYE(KRHP) = RHPD(KRHP)
      IHRE(KRHP) = RHPH(KRHP) + IPTE
106   CONTINUE
C  ELIMINATE HYDROGRAPH OVERLAPPING
      NRHP1 = NRHP - 1
      IF(NRHP1 .EQ. 0) GO TO 109
      DO 108 KRHP = 1, NRHP1
      IF((IDYE(KRHP) .GT.  IDYB(KRHP+1) .AND. (.NOT. ((IDYE(KRHP) .GE.
     1  274 .AND. IDYB(KRHP+1) .LE. 273) .OR. IDYE(KRHP) .EQ.366))) .OR.
     2  (IDYE(KRHP) .EQ. IDYB(KRHP+1).AND.IHRE(KRHP) .GT. IHRB(KRHP+1)
     3  )) GO TO 107
      GO TO 108
 107  IDYE(KRHP) = IDYB(KRHP+1)
      IHRE(KRHP) = IHRB(KRHP+1)
 108  CONTINUE
 109  IF(IDYB(1) .LE. 273 .AND. RHPD(1) .GE. 274 .AND. RHPD(1) .NE. 366)
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```
    1  GO TO 110
       GO TO 111
 110   IDYB(1) = 274
       IHRB(1) = 1
 111   IF(IDYE(NRHP) .GE. 274 .AND. RHPD(NRHP) .LE. 273 .AND. IDYE(NRHP)
    1   .NE. 366) GO TO 112
       GO TO 113
 112   IDYE(NRHP) = 273
       IHRE(NRHP) = 24
 113   CONTINUE
       DO 114 KRHP = 1,NRHP
       WRITE(6,1) KRHP,IDYB(KRHP),IHRB(KRHP),IDYE(KRHP),IHRE(KRHP)
  1    FORMAT(5X,'RUNOFF CONTRIBUTING TO RECORDED HYDROGRAPH',I2/10X,
    1   'BEGINS ON DAY',I4,' AT HOUR',I3/10X,'AND ENDS ON DAY',I4,
    2   ' AT HOUR',I3)
 114   CONTINUE
       RETURN
       END
       SUBROUTINE TIMERT(SSR,SRR,CTRI,NCTRI,KRHP,KPCH)
C  PERFORMS CHANNEL TIME ROUTING
       DIMENSION SSR(5,170),SRR(5,170),CTRI(99)
       DO 100 KHPT = 1,KPCH
 100   SRR(KRHP,KHPT) = 0.0
       KTRI = 1
 101   CONTINUE
       DO 102 KHPT = KTRI,KPCH
       NRTRI = KHPT -KTRI + 1
 102   SRR(KRHP,KHPT) = CTRI(KTRI)*SSR(KRHP,NRTRI) + SRR(KRHP,KHPT)
       KTRI = KTRI + 1
       IF(KTRI .LE. NCTRI) GO TO 101
       RETURN
       END
       SUBROUTINE DAYNXT(DAY,DPY)
C  DETERMINES NUMBER OF NEXT DAY OF THE YEAR
       INTEGER DAY,DPY
       DAY = DAY+1
       IF(DAY .EQ. 366) DAY = 1
       IF(DAY .EQ. 60 .AND. DPY .EQ. 366) DAY = 366
       IF(DAY .EQ.367) DAY=60
       RETURN
       END
       SUBROUTINE EVPDAY(DPET,EMAET)
C  DETERMINES DATED PAN EVAPORATION TOTALS
       DIMENSION DPET(366)
       RETURN
       END
       SUBROUTINE DAYOUT(VDCY,MEDWY,DPY)
C PRINTS TABLE OF DAILY VALUES
       DIMENSION MEDWY(12),VDCY(366),VDMD(12)
       INTEGER DATE,DAY,DPY
  100 WRITE(6,1)
    1 FORMAT(7X,3HDAY,7X,3HJUN,5X,3HJUL,5X,3HAUG,5X,4HSEPT,5X,3HOCT,5X,
    1   3HNOV,5X,3HDEC,5X,3HJAN,5X,3HFEB,5X,3HMAR,5X,3HAPR,5X,3HMAY)
       MEDWY(3)=0
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```
      DO 104 DATE = 1,28,1
      IF(MOD(DATE,5) .NE. 1) GO TO 102
      DO 101 KMO = 1,12
      DAY = MEDWY(KMO) + DATE
  101 VDMD(KMO) = VDCY(DAY)
      WRITE(6,2) DATE,VDMD(12),(VDMD(KWD),KWD=1,11)
    2 FORMAT(1H0,3X,I6,3X,12F8.1)
      GO TO 104
  102 DO 103 KMO=1,12
      DAY=MEDWY(KMO) + DATE
  103 VDMD(KMO) = VDCY(DAY)
      WRITE(6,3) DATE,VDMD(12),(VDMD(KWD),KWD=1,11)
    3 FORMAT(1X,3X, I6,3X,12F8.1)
  104 CONTINUE
      IF(DPY .NE. 366) GO TO 106
      DATE = 29
      VDCY(60) = VDCY(366)
      DO 105 KMO = 1,12
      DAY = MEDWY(KMO) + DATE
  105 VDMD(KMO) = VDCY(DAY)
      WRITE(6,3) DATE,VDMD(12),(VDMD(KWD), KWD=1,11)
      GO TO 107
  106 CONTINUE
      WRITE(6,4) VDCY(302),VDCY(333),VDCY(363),VDCY(29),VDCY(88),
     1VDCY(119),VDCY(149),VDCY(180),VDCY(210),VDCY(241),VDCY(272)
    4 FORMAT(1X,7X,2H29,3X,4F8.1,8X,7F8.1)
  107 CONTINUE
  108 WRITE(6,5) VDCY(303),VDCY(334),VDCY(364),VDCY(30),VDCY(89),
     1VDCY(120),VDCY(150),VDCY(181),VDCY(211),VDCY(242),VDCY(273)
    5 FORMAT(1X,7X,2H30,3X,4F8.1,8X,7F8.1)
      WRITE(6,6) VDCY(304),VDCY(365),VDCY(31),VDCY(90),VDCY(151),
     1VDCY(212),VDCY(243)
    6 FORMAT(1H/,7X,2H31,3X,F8.1,8X,2F8.1,8X,F8.1,8X,F8.1,8X,2F8.1)
      MEDWY(3) = 365
      RETURN
      END
      SUBROUTINE PREPRD(RGPM,DRHP,DAY,HOUR,DPY,PRD,PEP,PRH)
C  DIVIDES HOURLY PRECIPITATION TOTALS AMONG PERIODS FOR SMALL BASINS
      DIMENSION PE4P(4),DRHP(366,24)
      INTEGER DAY,DPY,HOUR,PRD
      PEP=0.0
      IF(PRH .EQ.0.0) RETURN
      IF(PRD .EQ. 1) GO TO 100
      PEP = PE4P(PRD)
      RETURN
  100 LHOUR = HOUR-1
      LDAY = DAY
      IF(LHOUR .GE. 1 ) GO TO 101
      LHOUR = 24
      LDAY=DAY-1
      IF(LDAY .EQ. 0) LDAY=365
      IF(LDAY .EQ. 365) LDAY=59
      IF(LDAY .EQ. 59 .AND. DPY .EQ. 366) LDAY=366
  101 PRLH = RGPM*DRHP(LDAY,LHOUR)
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      NHOUR = HOUR+1                                                    SHM19980
      NDAY = DAY                                                        SHM19990
      IF(NHOUR .LE. 24) GO TO 102                                       SHM20000
      NHOUR=1                                                           SHM20010
      CALL DAYNXT(NDAY,DPY)                                             SHM20020
  102 PRNH=RGPM*DRHP(NDAY,NHOUR)                                        SHM20030
      IF(PRH .GT. PRLH .AND. PRH .GT. PRNH) GO TO 103                   SHM20040
      GO TO 104                                                         SHM20050
  103 PE4P(1) = 0.10                                                    SHM20060
      PE4P(2) = 0.28                                                    SHM20070
      PE4P(3) = 0.46                                                    SHM20080
      PE4P(4) = 0.16                                                    SHM20090
      GO TO 108                                                         SHM20100
  104 IF(PRH .LT. PRLH .AND. PRH .LT. PRNH) GO TO 105                   SHM20110
      GO TO 106                                                         SHM20120
  105 PE4P(1) = 0.28                                                    SHM20130
      PE4P(2) = 0.10                                                    SHM20140
      PE4P(3) = 0.16                                                    SHM20150
      PE4P(4) = 0.46                                                    SHM20160
      GO TO 108                                                         SHM20170
  106 IF(PRNH .GE. PRLH) GO TO 107                                      SHM20180
      PE4P(1) = 0.46                                                    SHM20190
      PE4P(2) = 0.16                                                    SHM20200
      PE4P(3) = 0.28                                                    SHM20210
      PE4P(4) = 0.10                                                    SHM20220
      GO TO 108                                                         SHM20230
  107 PE4P(1) = 0.10                                                    SHM20240
      PE4P(2) = 0.28                                                    SHM20250
      PE4P(3) = 0.16                                                    SHM20260
      PE4P(4) = 0.46                                                    SHM20270
  108 DO 109 KPRD = 1,4                                                 SHM20280
  109 PE4P(KPRD) = PE4P(KPRD)*PRH                                       SHM20290
      PEP=PE4P(1)                                                       SHM20300
      RETURN                                                            SHM20310
      END                                                               SHM20320
```